Physical Hazards: Plant

Core Body of Knowledge for the Generalist OHS Professional

Safety Institute of Australia Ltd

Australian OHS Education Accreditation Board

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The OHS Body of Knowledge for Generalist OHS Professionals has been developed under the auspices of the **Health and Safety Professionals Alliance**

The Technical Panel established by the Health and Safety Professionals Alliance (HaSPA) was responsible for developing the conceptual framework of the OHS Body of Knowledge and for selecting contributing authors and peer-reviewers. The Technical Panel comprised representatives from:

The Safety Institute of Australia supported the development of the OHS Body of Knowledge and will be providing ongoing support for the dissemination of the OHS Body of Knowledge and for the maintenance and further development of the Body of Knowledge through the Australian OHS Education Accreditation Board which is auspiced by the Safety Institute of Australia.

Synopsis of the OHS Body Of Knowledge

Background

A defined body of knowledge is required as a basis for professional certification and for accreditation of education programs giving entry to a profession. The lack of such a body of knowledge for OHS professionals was identified in reviews of OHS legislation and OHS education in Australia. After a 2009 scoping study, WorkSafe Victoria provided funding to support a national project to develop and implement a core body of knowledge for generalist OHS professionals in Australia.

Development

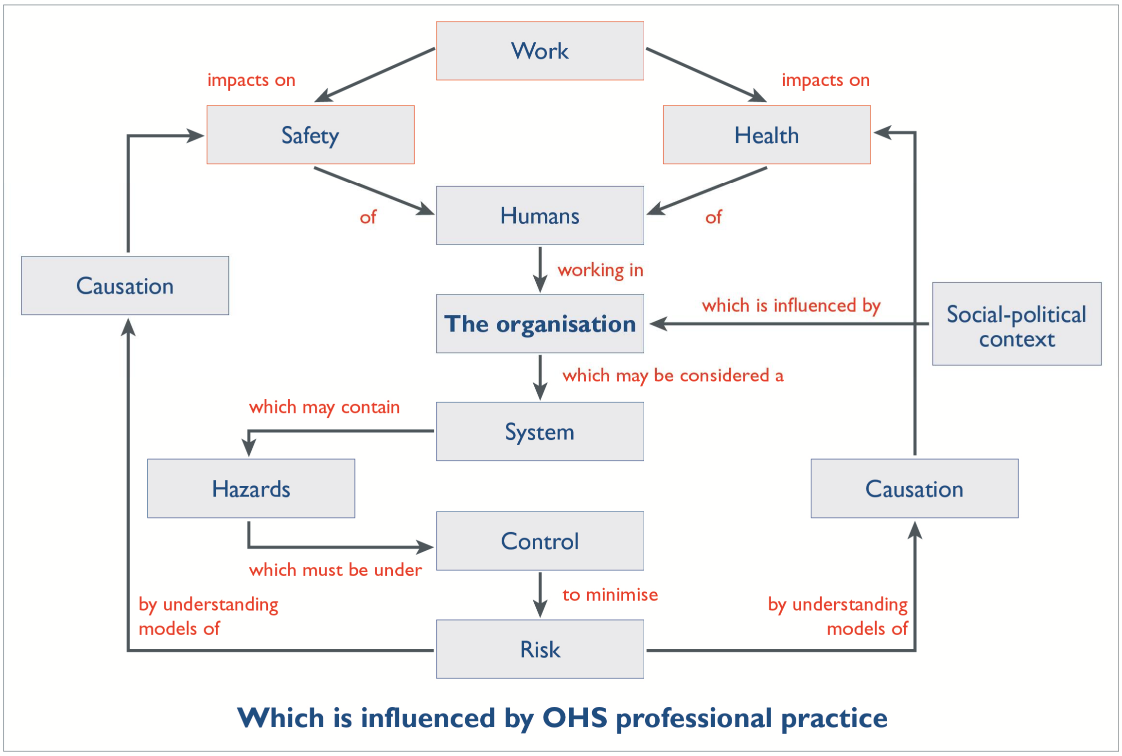
The process of developing and structuring the main content of this document was managed by a Technical Panel with representation from Victorian universities that teach OHS and from the Safety Institute of Australia, which is the main professional body for generalist OHS professionals in Australia. The Panel developed an initial conceptual framework which was then amended in accord with feedback received from OHS tertiary-level educators throughout Australia and the wider OHS profession. Specialist authors were invited to contribute chapters, which were then subjected to peer review and editing. It is anticipated that the resultant OHS Body of Knowledge will in future be regularly amended and updated as people use it and as the evidence base expands.

Conceptual structure

The OHS Body of Knowledge takes a ćconceptualô approach. As concepts are abstract, the OHS professional needs to organise the concepts into a framework in order to solve a problem. The overall framework used to structure the OHS Body of Knowledge is that:

> **Work** impacts on the **safety** and **health** of humans who work in **organisations**. Organisations are influenced by the **socio-political context**. Organisations may be considered a **system** which may contain **hazards** which must be under control to minimise **risk**. This can be achieved by understanding **models causation** for safety and for health which will result in improvement in the safety and health of people at work. The OHS professional applies **professional practice** to influence the organisation to being about this improvement.

This can be represented as:



Audience

The OHS Body of Knowledge provides a basis for accreditation of OHS professional education programs and certification of individual OHS professionals. It provides guidance for OHS educators in course development, and for OHS professionals and professional bodies in developing continuing professional development activities. Also, OHS regulators, employers and recruiters may find it useful for benchmarking OHS professional practice.

Application

Importantly, the OHS Body of Knowledge is neither a textbook nor a curriculum; rather it describes the key concepts, core theories and related evidence that should be shared by Australian generalist OHS professionals. This knowledge will be gained through a combination of education and experience.

Accessing and using the OHS Body of Knowledge for generalist OHS professionals

The OHS Body of Knowledge is published electronically. Each chapter can be downloaded separately. However users are advised to read the Introduction, which provides background to the information in individual chapters. They should also note the copyright requirements and the disclaimer before using or acting on the information.

Physical Hazards: Plant

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Physical Hazards: Plant

Abstract

Machinery, equipment, appliances or tools that can be generically grouped as ‘plant’ are ubiquitous in most workplaces. While many hazards are associated with such plant, this chapter focuses on the hazards associated with the moving parts of machinery, which have the potential to cause injury by crushing, shearing, entangling, trapping, hitting or abrading, or through the uncontrolled release of pressure. Most of these ‘kinetic energy’ or ‘potential energy’ related injuries are associated with fixed plant; however, a significant number of these injuries arise from use of powered equipment and tools in workshop, kitchen, office and garden workplaces. Identifying these hazards and assessing the associated risk requires knowledge of how kinetic and potential energy behave as well as factors at the machine-human interface that may lead to loss of control of the energy. Control strategies for these hazards have evolved from the simple approach of fencing in dangerous machine parts to a more sophisticated systematic approach involving: elimination or minimisation of the risk through design; engineering controls to prevent access to hazardous zones or to protect workers who have to access hazardous zones; administrative controls, including provision of information, training and instruction; and procedural approaches, such as Permit To Work and lockout/tagout systems. In developing or monitoring such controls, the generalist Occupational Health and Safety (OHS) professional must remain aware of the ways such protections can be defeated or break down.

Keywords:

plant, machinery, equipment, guard, energy, injury, safety

Contents

1 Introduction

Plant ï defined in the national model *Work Health and Safety Act* (WHSA s 4) as ñany machinery, equipment, appliance, container, implement and toolò (Safe Work Australia, 2011) ï is a part of nearly all workplaces. As in the Victorian Occupational Health and Safety Regulations (s 3.5.1) (WorkSafe Victoria, 2007), this definition can be expanded to include:

- plant that processes material by way of a mechanical action that
  - cuts, drills, punches or grinds the material
  - presses, forms, hammers, joins or moulds the material
  - combines, mixes, sorts, packages, assembles, knits or weaves the material
- plant that lifts or moves people or materials (e.g. conveyors, robots, pumps)
- pressure equipment (e.g. boilers, air receivers, compressors, hydraulic hoses and cylinders)
- lasers
- explosive-powered tools
- turbines
- amusement structures.[1]

Despite a high level of regulation, the use of such plant is associated with a high number of workplace fatalities and injuries.

This chapter is concerned with hazards associated with fixed plant and equipment across all industries. It focuses on hazards associated with moving machine parts and stored energy components, including pressure. Other types of energy associated with mechanical plant ï including acoustic energy (noise); chemical energy associated with chemicals used to operate and maintain machinery, and from emissions; thermal energy from fuels or friction; and human energy required for posture, movement and operation of machinery ï are discussed in separate chapters.

2 Historical perspective

Wide exposure of people to machinery-related hazards began during the Industrial Revolution (mid-18th to mid-19th centuries) when various forms of energy were harnessed through the use of machines in mining, manufacturing, agriculture, processing and transportation. Initially, the use of moving water as an energy source in the milling

[1] This definition includes plant defined as mobile plant; see *BoK* Physical Hazards: Mobile Plant

industry exposed workers to a variety of mechanical hazards. With the introduction of steam power, hazards associated with pressure became evident as inadequacies in design and materials led to boiler explosions and catastrophic consequences. As electric motors became available, machinery of increasing size and power proliferated, with the result that more people were exposed to machinery hazards more of the time.

In the British legal system, safety legislation began in the early 1800s with the Factories Acts; a primary focus was to protect children through the introduction of a minimum age for work and limiting work hours (see, for example, Nardinelli, 1980). One of the earliest references to machine safety was in the UK *Factories Act 1844* where reference was made to fencing machinery to prevent access to hazards. In Australia, one of the earliest references to machinery safety was in the *Factories and Shops Act 1885* (Vic), which referred to competency requirements for boiler and steam engine operators, and the need for fencing machinery.

Despite enormous development in the types and power of machinery, the types of hazards associated with machinery have not changed significantly since the 1800s. What has changed significantly is the knowledge and availability of controls to prevent injury from these hazards.

The 1972 Robens report[2] changed the face of OHS legislation in Britain, and subsequently in Australia, by expressing duties in performance or outcome-based terms, i.e. what had to be achieved rather than prescriptive directions as to how to achieve the required level of safety (see, for example, NRCOHSR, 2002). This style of legislation also had a profound effect on the development of standards; none more so perhaps than those dealing with machinery-based mechanical hazards.

3 Extent of the problem

National workersô compensation claims data (Safe Work Australia, 2006ï 07) indicate that for the year 2006ï 07[3] a total of 14,640 claims (10.9% of all claims) related to use of machinery (mainly fixed plant) and powered equipment, tools and appliances; also, there were 22 fatalities associated with this use, and 67.2% of claims incurred two or more weeks of lost work time. The most common types of injury for plant-related claims were contusions/open wounds and fractures/dislocations. (Table 1)

[2] See *OHS BoK* Socio-Political Context: OHS Law and Regulation in Australia
[3] This was the most up-to-date complete data available at the time of writing.

Table 1: Types of injury associated with use of plant (Safe Work Australia, 2006–07)

Injury	Machinery (mainly fixed plant) % claims	Powered equipment, tools and appliances % claims
Contusion/open wound	31.5%	18.2%
Fracture/dislocation	10.4%	5.1%
Amputation	3.6%	0.7%
Multiple/internal/vertebral column/foreign body in eye, ear, nose	1.0%	0.6%
Other*	53.7%	75.4
	100%	100%

* Includes burns, electrocution, musculoskeletal injuries and hearing loss associated with use of plant; these hazards and their mechanisms are discussed in other chapters.

Not surprisingly, the largest proportion of injury claims (40% of those related to fixed plant and 21% of those related to powered equipment) were in the Manufacturing industry. Construction, Retail Trade, and Property and Business Services all incurred at least 7% of claims related to both plant and powered equipment, while Government Administration and Defence, and Health and Community Services each incurred 9% of claims for powered equipment (Table 2).

Table 2: Claims for plant hazards by industry (Safe Work Australia, 2006–07)

Industry	Machinery (mainly fixed plant)		Powered equipment, tools and appliances	
	No. claims	% claims	No. claims	% claims
Agriculture, Forestry and Fishing	285	3.5	110	1.2
Mining	175	2.1	70	1.1
Manufacturing	3250	39.9	1340	20.6
Electricity, Gas and Water Supply	90	1.1	55	0.8
Construction	970	11.9	720	11.1
Wholesale Trade	585	7.2	245	3.8
Retail Trade	705	8.6	525	8.1
Accommodation, Cafes and Restaurants	220	2.7	335	5.1
Transport and Storage	555	6.8	255	3.9
Communication Services	50	0.6	45	0.7
Finance and Insurance	10	0.1	185	2.8
Property and Business Services	590	7.2	730	11.2

Government Administration and Defence	90	1.1	600	9.2
Education	105	1.3	290	4.5
Health and Community Services	235	2.9	600	9.2
Cultural and Recreational Services	75	0.9	145	2.2
Personal and Other Services	115	1.4	225	3.5
Not stated	20	0.2	15	0.2
Total*	8135	99.5	6505	99.2

*The sum of the claims for each column may not equal the total listed as the number of claims for each category have been rounded to the nearest 5 to maintain confidentiality.

However, these injuries result from a range of mechanisms. As the focus of this chapter is hazards created by moving parts of plant, the most relevant mechanisms of injury for plant hazards are being hit by moving objects and hitting objects with part of the body; together these resulted in 5730 claims or 4.3% of all claims. Of these claims, 80% of injuries were related to being trapped by/trapped between/hit by or hitting moving objects (Safe Work Australia, 2006ï 07).

Examination of the claims data revealed that the types of fixed plant most frequently associated with injury were cutting/sawing equipment and conveyers, which together accounted for 47% of plant-related injuries arising from ókinetic energyô (Table 3). Workshop equipment was the type of powered appliance that most frequently resulted in these types of injury. Of the 22 fatalities associated with plant, 10 occurred on/around conveyers and two were related to workshop equipment.

Table 3: Percentage of claims arising from ‘kinetic energy’ for types of plant

		Hitting objects with part of the body No. claims	Being hit by moving objects No. claims	Total for type of plant No. claims	% Plant claims
Machinery	Cutting/sawing	530	970	1500	26.2%
	Conveyers	190	1020	1210	21.1%
	Crushing/ pressing	60	350	410	7.2%
	Electrical	45	65	110	1.9%
	Other	230	545	775	13.5%
	Total for machinery	*1055*	*2950*	*4005*	*70%*
Powered equipment, tools and appliances	Workshop	420	545	964	16.8%
	Kitchen	130	185	315	5.49%
	Office	35	50	85	1.5%
	Garden	65	95	160	2.8%
	Pressure	20	110	130	2.3%
	Other	20	50	70	1.2%
	Total for equipment, etc.	*270*	*490*	*1724*	*30%*
	Total	1745	3985		
Total ókinetic energyô claims for plant				5729	99.99%

(Derived from Safework Australia, 2006ï 07)

4 Understanding plant hazards

Understanding plant and machinery hazards requires an understanding of kinetic and potential energy.

> *Kinetic energy hazards* involve ñthings in motionò and ñimpact,ò and are associated with the collision of objects in relative motion to each other. This would include impact of objects moving toward each other, impact of a moving object against a stationary object, falling objects, flying objects, and flying particles.
> *Potential energy hazards* involve ñstored energy.ò This includes things that are under pressure, tension or compression; or things that attract or repulse one another. Potential energy hazards involve things that are ñsusceptible to sudden unexpected movement.ò Hazards associated with gravity are included in this category and pertain to potential falling objects or persons. This category also includes the forces of gravity transferred biomechanically to the human body during manual lifting. (Nelson & Associates, 2010)

Also required is an understanding that injury occurs when the intensity of energy transferred exceeds the energy threshold of the person, and how factors associated with the human-machine interface contribute to risk of loss of control of the energy. The goal is to eliminate or minimise human-machine-interface failures (see, for example, EASHW, 2009; Sudano, 1994).

4.1 An energy approach

The Energy Damage Model (Viner, 1991)[4] provides a framework for understanding the hazards associated with machinery in terms of the energy sources within the system.[5] For example, electrical energy may be used to operate and drive mechanical components of a machine. In addition to specific hazards associated with the electricity,[6] electrical energy may be transformed into different types of energy, each representing a different type of hazard. Typically, the most readily identifiable hazards are those associated with the kinetic energy of moving components. An enormous variety of shapes and sizes of machine components operating in linear or rotational motion have the potential to cause damage to people. Generally, recognition of these types of hazards is simple as the movement of the components is often visible. Also, a person may be damaged by stationary machine components; for example, a sharp edge of a machine may cause a laceration if contact is made by a moving person (through their own kinetic energy).

Electrical energy may be transformed into forms of energy other than kinetic energy. For example, it may be transformed into potential energy ï represented by stored pressure of gases or liquids as in pneumatic and hydraulic systems, or by stored energy in machine components such as springs ï or gravitational potential energy, such as a ram being held above the die in a press. Recognition of the hazards associated with such potential energy is more difficult as the hazards may not be readily visible. In most cases, a higher level of technical expertise and a greater understanding of specific machine design are required to identify hazards associated with stored energy.

Other types of energy associated with mechanical plant include acoustic energy (noise), chemical energy associated with chemicals used to operate and maintain machinery and from emissions, thermal energy from fuels or friction, and human energy required for posture, movement and operation of machinery.

4.2 Injury process and outcomes

In line with Vinerôs (1991) Energy Damage Model, hazards will cause an injury when the intensity of energy transferred to a person exceeds the threshold of the personôs resistance at the point of contact. The terminology associated with the Energy Damage Model is not well understood outside the OHS profession resulting in potential outcomes often being described as hazards. For example, *AS 4024.1201 Safety of Machinery: General Principles*

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[4] See also *BoK*: Models of Causation: Safety
[5] See *BoK* Hazard as a Concept
[6] See *BoK* Hazards: Electricity

– *Basic Terminology and Methodology* and *AS 4024.1301 Safety of Machinery: Principles of Risk Assessment* (SA, 2006) describe hazards using the potential outcome as the descriptor (e.g. crushing hazard), even though both Standards reference energy as the underlying source for potential harm. The OHS professional should recognise crushing as an outcome, not the hazard, and the severity of the outcome as being directly related to the amount of energy.

Injuries associated with moving parts of plant commonly arise from the following outcomes:

- Crushing: where a person could be crushed between one or more moving machine components (e.g. between the ram and die of a press)
- Shearing: where a person could be caught between two or more components moving past each other (e.g. scissor action)
- Cutting or severing: where a person could contact sharp surfaces or rapidly moving components
- Entanglement: where a person could become entangled in a rotating or moving component (e.g. a roller or conveyor)
- Drawing-in or trapping: where a person could be drawn in by a rotating or moving surface or surfaces (e.g. between two in-running rollers or between one roller and a fixed surface)
- Impact: where a person could be struck by an object, either a controlled moving machine component or uncontrolled ejected material from a machine
- Stabbing or puncture: where a person could contact a sharp machine protuberance, with either machine or person in motion
- Friction or abrasion: where a person could contact a rough surface with either the surface or person in motion
- High-pressure fluid injection (penetration of the skin) or ejection: where a person may be struck by hydraulic fluid, steam or air.

4.3 Risk factors

AS 4024.1201 General Principles ï *Basic Terminology and Methodology* (SA, 2006) provides a list of important contributory risk factors for mechanical hazards associated with plant including:

- Shape, e.g. cutting elements, sharp edges, angular parts, even if stationary; de-burred sheet metal edges, smooth rather than rough surfaces, protruding parts to catch clothing

- Relative location, which can create crushing, shearing, entanglement zones when elements are moving, e.g. distance between in-running rollers for feeding material into a printing press, accessible by the press operator
- Stability against overturning (considering kinetic energy), e.g. suitable geometry of base, weight distribution, vibration, external forces such as wind
- Mass and stability (potential energy of elements that can move under the effect of gravity, e.g. press ram or hoist platform held above other components during machine operation, cranes
- Mass and velocity (kinetic energy of elements in controlled or uncontrolled motion), e.g. from fast-moving light-weight components to slow-moving heavy components
- Acceleration and deceleration (components that may accelerate quickly from rest)
- Inadequate mechanical strength, which can generate hazardous breakages or bursts, e.g. grinder wheel disintegration or drive chain breakage, structural failure through loads and fatigue
- Potential energy of elastic elements (springs), or liquids or gases under pressure or vacuum, e.g. tyres under pressure, boilers, air receivers, hydraulic hoses, compressed air hoses.

Although there are many methods of quantifying elements of these contributory factors, it is difficult to quantify the minimum transfer of energy required to cause an injury. *AS 4024.1601 Guards* (SA, 2006) provides only limited assistance in this area; for example, to prevent injury from a power-operated guard, it stipulates 75 Newtons (approximately 7.5 kg force) and 4 Joules as the maximum force and energy when no protective device is fitted. Consequently, it is necessary to look to other Australian and international standards for guidance. For example, *AS 4343ï 2005 Pressure Equipment – Hazard Levels* (SA, 2005) provides guidance on determining hazard levels for various types of pressure vessels, which in turn determine the level of control; 50kPa has been selected as the minimum pressure to exempt such vessels from special requirements. Some industry bodies have developed guidance on machine safety that quantifies some of the contributory factors. For example, the *Plascare Manual* for the Plastics Industry code (PACIA,1996) stipulates specific controls for pressure piping over 5MPa.

4.4 Human-machine interface

Notwithstanding the importance of the machine-specific factors, the key factor in determining the risk presented by mechanical hazards of plant is the human-machine interface throughout the life cycle of the machine. It is vital to understand where, when and how people are likely to interact with the machine. Stages of the life cycle may include the machine construction, transportation, installation, commissioning, operation, maintenance, troubleshooting, cleaning, repair, decommissioning and removal. While mechanical hazards may be present at each stage, it is likely that exposure to them will vary; for example, during normal operation of a machine, mechanical hazards associated with kinetic energy are likely to be present, such as rollers turning, presses closing or conveyors moving. Exposure to these hazards may occur during normal operation of a machine (e.g. when manually loading cardboard flats into a carton-making machine) and during abnormal operation (e.g. when a machine jams or malfunctions and an intervention is required).

An often-overlooked area is the exposure of technical, maintenance and engineering personnel to mechanical hazards during routine maintenance, machine setting, troubleshooting and repairs. It is during these activities that exposure to hazards generated by stored energy is most common (e.g. compressed air, hydraulic pressure, spring tension or simply components held against gravity).

4.5 Section summary

It is important that the generalist OHS professional understands that, despite the extensive and often generalised use of the term, ‘hazard’ has a specific meaning for machinery and equipment, involving the correlation between the amount of energy possessed or required by the machine to do its work and the threshold of resistance to that energy possessed by the human. As indicated by the example from *AS 4024.1601* (section 4.3), all but the simplest of machines and processes require or possess energy far exceeding human resistance. This means that if a person is subject to any of the outcomes or contributory factors described earlier significant damage is likely to occur. As shown in section 3, such damage impacted on at least 14,640 people who were injured or killed in one year as a result of working with fixed plant or equipment.

5 Legislation and standards

The national model *Work Health and Safety Act* (WHSA ss 21–26) (Safe Work Australia, 2011) and the draft Work Health and Safety Regulations (Safe Work Australia, 2010) place extensive obligations regarding plant on persons conducting a business or undertaking involving management or control of plant, design, manufacture, import, supply or installation of plant. Depending on the particular role, the responsibilities include ensuring as far as practicable that:

- The plant is designed, manufactured, installed, constructed and commissioned so as to be without risk to the health and safety of persons
- Calculations, analysis, testing or examination that may be necessary are carried out
- Adequate information is provided to appropriate persons.

The scope of the obligations cover those who:

- Manufacture or assemble the plant for the purpose for which it is intended
- Carry out any reasonably foreseeable activity at the workplace in relation to assembly or use of the plant
- Properly store the plant
- Decommission, dismantle or dispose of the plant
- Are at or in the vicinity of the plant.

These obligations are in addition to the primary duty of care on a person conducting a business or undertaking (PCBU) that requires, so far as is reasonably practicable, the health and safety of persons engaged in work influenced or directed by the person or who are at the workplace (WHSA s 19).

In addition to providing detail on the general obligations of designers, manufacturers, installers and others, the draft regulations place additional obligations on PCBUs regarding risk-control measures, including prevention of unauthorised modification to plant, proper use of plant, guarding, plant controls, keeping records related to use of plant, and providing information, training, instruction and supervision to those who use the plant (WHSR ss 5.1.21ï 5.1.33). Under the draft regulations, the general obligations for plant are extended to pressure vessels with the added requirement for regular inspection by a competent person (WHSR s 5.1.43).

6 Control of mechanical hazards associated with plant

Strategies to control risk associated with plant have evolved from the 19th century requirement to fence dangerous parts of machinery to a more sophisticated, systematic approach that focuses on: elimination or minimisation of risk at the design stage, and implementation of engineering controls to prevent access to hazardous zones or to protect workers who are required to access hazardous zones; these processes are supported by administrative controls, such as testing of the condition of plant, and provision of information, instruction and training, and Permit to Work systems.

6.1 Elimination or minimisation through design

Opportunities to control hazards begin at the machine-design stage. The use of low-speed, low-pressure or low-energy components may reduce risk from mechanical hazards. Also, clever design can be used to eliminate direct access to machine hazards (e.g. by enclosing the hazards within the body of the machine, and by providing controls and machine adjustments away from the hazards) and to reduce exposure of maintenance personnel by positioning equipment so that it can be serviced and repaired without the need to access hazardous areas or operate the machine during set up or maintenance. There is an expectation that machinery will be designed and constructed to recognised engineering standards (materials, stresses and tolerances) with suitable built-in safety factors to minimise machine-component failure.

The national model legislation recognises the importance of design and the need to maintain engineering quality by identifying types of plant that require registration of the design with the responsible government authority. These design registrations usually relate to plant that would have catastrophic consequences for failure; for example, pressure equipment such as boilers and air receivers (potential for explosion) and lifts, hoists, cranes and scaffolding (potential for collapse or falling).

6.2 Engineering controls

6.2.1 Guarding to prevent access

After design, the most common method of risk control for mechanical hazards is to prevent a person entering the zone where the damaging energy can be transferred to the person, or controlling the damaging energy when a person needs to enter the zone. This is typically achieved through the provision of guarding.

The draft model regulations (WHSR s 5.1.7) set out a hierarchy of guarding that requires the designer who uses guarding to prevent access to a hazardous zone to ensure, as far as is reasonably practicable, that:

- A permanently fixed guard is used where access is not required
- An interlocked guard is used where access is required
- A physical barrier that can only be altered or removed with tools is only used where a fixed guard or interlocked guard is not reasonably practicable
- A presence-sensing system is used only where a fixed guard, interlocked guard or physical barrier that can only be removed with tools is not reasonably practicable.

AS 4024.1601 Guards – General Requirements for the Design and Construction of Fixed and Movable Guards and *AS 4024.1602 Principles for Design and Selection (Design of Controls, Interlocks and Guarding)* (SA, 2006) provide significant detail on the types, design and selection of guards for different hazards and exposures. They describe the circumstances most appropriate for the use of:

- Fixed guards (a permanent guard, or guard that requires tools to remove)
- Self-closing (e.g. movable guard on circular saw) and adjustable guards (e.g. telescopic guard on pedestal drill)
- Movable guards with interlocking (e.g. when the guard is opened a stop signal is sent so the mechanical hazard ceases and while the guard remains open the mechanical hazard cannot be started)

- Movable guards with interlocking and guard locking (e.g. the guard cannot be opened until the mechanical hazard ceases).

The effectiveness of guarding to prevent access to hazardous zones relies on the application of knowledge of ergonomics. Human body sizes and shapes determine the size of the guard and where to place the guard to prevent access to the hazard. Detailed guidance on safety distances based on anthropometric data is provided in *AS 4024.1801 Safety Distances to Prevent Danger Zones Being Reached by the Upper Limbs, AS 4024.1802 Safety Distances to Prevent Danger Zones Being Reached by the Lower Limbs* and *AS 4024.1803 Minimum Gaps to Prevent Crushing of Parts of the Human Body* (SA, 2006). This data is derived from specific populations and may not necessarily account for the employees in a particular workplace. For example, the guidance provided in *AS 4024.1801* is derived from a European population and may not account for the influence of other ethnic groupings in a workplace.

AS 4024.1602 Principles for Design and Selection in particular provides guidance on the type of interlocking and the selection of interlocking devices. Two types of interlocking are used: power interlocking and control interlocking. In power-interlocking devices, the stop command from the interlocking device removes the energy supply to any hazardous motions (i.e. it turns the power OFF), whereas control interlocking interrupts the machine control circuit so that hazardous motion is stopped and prevented from being restarted, but the energy supply is still ON.

While all interlocking devices perform the same basic function, they are not a óone size fits allô proposition. Some devices are more suited to particular roles or operational environments than others and need to be chosen and installed accordingly. The various types of interlocking devices are:

- Position detectors: often referred to as limit switches or micro switches and may be plunger or lever operated
- Tongue-operated switches: where a tongue or actuator attached to the guard enters the switch when the guard is closed
- Non-contact switches: which do not have any external moving parts, but rely solely on detecting the presence of detectable material, magnet or coded address
- Trapped-key switches: where the master key carries out a power or control interlock function at the main operating console and is then used to carry out a purely mechanical unlocking function at the guard, in turn becoming ótrappedô in the lock until the guard is closed again
- Plug and socket devices: similar in principle to any plug and socket; not commonly used and limited generally to unique applications.

Underpinning the performance of all the safeguarding strategies is the Category of the Safety Related Parts of the Control System (SA, 2006), which refers to the reliability of fault detection and the fault resistance of the elements that make up the Safety Control System. It is related generally to the machine control system ï the Electrical, Electronic and Programmable Electronic (E/E/PE) system ï but also has application to mechanical elements of the control system (e.g. clutch and brake components, physical guarding). The performance requirements for the Categories are set out in *AS 4024.1501 General Principles (Design of Safety-related Part of Control Systems)* and *AS 4024.1502 Validation (Design of Safety-related Parts of the Control System)* (SA, 2006).

6.2.2 Protection of personnel entering hazardous zones

During production and maintenance activities, access is sometimes required past guards so it is important that protection is provided to personnel entering potential hazard zones. This may be by isolation of energy sources, presence-sensing systems or specifically designed machine controls.

Isolation

Isolation of energy sources and dissipation or containment of stored energy is required to prevent hazards arising whilst personnel are in the hazard zone. *AS 4024.1603 Prevention of Unexpected Start-up* (SA, 2006) provides guidance in this area. Isolation is usually an integral part of a Permit To Work system (section 6.4.2).

Presence-sensing systems

Presence-sensing systems can be an effective risk control when frequent access is required to machinery whilst it is operating. Protective equipment such as light curtains, pressure mats and laser-scanning devices are becoming more commonly used, particularly as technological developments provide greater confidence in the reliability of safety-related control systems. Guidance on the effective positioning of presence-sensing systems is provided in *AS 4024.1801*.

Machine controls

Under some circumstances exposure to plant-related hazards can be reduced by the use of machine controls such as:

- *Two-handed controls*, which require an operator to use both hands simultaneously to operate a machine (and therefore generate the hazard)
- *Hold-to-run controls*, which require an operator to continuously activate a control to move or operate a machine; operators can still be exposed to mechanical hazards whilst using the control, but are able to stop the machine instantly by releasing the control button or lever

- *Inch controls*, which allow a machine to operate over a small defined distance (e.g. an inch control may allow a roller to rotate a few degrees for each activation of the control); holding down the control should not allow the machine to continue operating
- *Crawl controls*, which allow a machine to run at very slow speed.

Each of these controls may be used in defined circumstances to reduce either the exposure to hazards or the potential exposure consequences.

6.3 Defeat of safeguarding systems

Many safeguarding systems fail in practice because persons have been able to defeat or disable the system. Frequently this results in serious injury, even fatality. The draft model WHS regulations place particular emphasis on the prevention or defeat of safeguarding systems by requiring the designer to ensure guarding is ñdesigned to make by-passing or disabling of the guarding, whether deliberately or by accident, as difficult as is reasonably possibleò (WHSR s 5.1.7). Also, there is an obligation on the PCBU to ñensure that measures are implemented to prevent alterations or interference with the plant that are not authorised by that personò (WHSR s 5.1.24).

In addition AS 4024.1 (SA, 2006) includes numerous references to the possibilities for misuse or defeat of machine safeguarding systems and provides guidance as to how to prevent or minimise such misuse. Bypassing or disabling of guarding is not restricted to bridging of circuits or defeat of interlocking devices; it also includes the opportunity for persons to reach over, under, through or around physical guarding as well as situations where persons can, and sometimes are required to, gain whole-body access into machinery and can become shut inside the guarded area. Persons can be motivated to defeat or disable a safeguarding system if it is perceived to make operation of the machine more difficult, slows the operation down or fails to provide safe and easy means to correct machine malfunctions or jam-ups, or setting and adjustments.

6.4 Administrative controls

In addition to good design and the use of guarding or machine controls, administrative controls are required to prevent exposure to machinery hazards. Although less reliable than design and engineering controls, administrative controls are an important part of the ópackageô for control of plant-related hazards.

6.4.1 Testing

The WHS legislation and Australian Standards refer to the testing, ongoing maintenance and routine inspection requirements to help manage plant-related risks. For example, the requirement to test pressure equipment is cited in the draft model regulations (WHSR s 5.1.43) and *AS/NZS 3788 Pressure Equipment – In-service Inspection* (SA/SNZ, 2006). Most legislative authorities no longer carry out formal inspections of this type of equipment as was common practice in the past by Boilers and Pressure Vessels Inspectors. These requirements are now the responsibility of the user or owner and are often overlooked. Fatigue and corrosion over time can render these systems unsafe; regular inspection and testing as prescribed is vital.

6.4.2 Permit to Work and lockout/tagout procedures

Administrative controls are often used to protect engineering, maintenance and cleaning personnel who may be required to access hazard zones inside normal guarding. The types of administrative controls commonly found in industry include Permit To Work and lockout/tagout. As these systems are dependent on human intervention, they are at the lower level of the risk-control hierarchy. Extensive knowledge of the machinery and the processes are required to establish the procedures, and their effectiveness relies on strict compliance by all personnel.

Permit to Work systems

A Permit To Work (PTW) requires that a permit be obtained from a competent person prior to undertaking certain tasks where personnel may be exposed to mechanical hazards. A PTW system gives the responsible person the opportunity to review work to be undertaken, identify hazards and ensure suitable controls are employed. A Job Safety Analysis (JSA) is often used to inform and determine the conditions of the permit. Specialised equipment may be required or isolation of energy sources may need to be undertaken prior to commencing the work.

Isolation and lockout/tagout systems

Many organisations employ a system of locking out energy sources prior to commencement of work. Less-effective systems simply involve tagging out isolators or controls (without locks) prior to accessing the machinery.

6.4.3 Information, instruction, training and supervision

Provision of information, instruction, training and supervision is an important strategy in controlling the risk associated with plant. In addition to the general duty to provide information, instruction, training and supervision (WHSA s 19.2f), the model Act and regulations include specific requirements for designers, manufacturers and suppliers to, on request, provide appropriate information. Also, information, training and instruction to protect users of plant must be provided prior to use of the plant (WHSR s 5.1.28). The information provided should include standard operating procedures as appropriate. Even where licensing of operators is required for certain types of high-risk plant, there should be training in the use of specific types of plant or specific procedures and assessment of competency. Determination of the extent of information, instruction and training provided (and the level of competency required) should take account of the nature and extent of supervision. The less supervision, and the more remote the supervision, the higher the level of information and competency required.

6.5 Personal protective equipment

While many operators of plant wear personal protective equipment (PPE), this is usually to protect against other hazards associated with the plant, such as hearing protection for noise produced by the machinery or eye protection against possible ejection of dust or swarf. There is little or no PPE that can protect against the kinetic energy of moving machine parts; indeed, when there is in-running movement of machine parts the wearing of gloves can increase the risk of entrapment.

7 Implications for OHS practice

Recognition and control of mechanical hazards is relevant to all industries using machinery. While mining, processing, construction, manufacturing, food, retail and logistics are obvious users of machinery, mechanical hazards are evident in many other industries (e.g. primary health, education, office buildings and emergency services). Consequently, all generalist OHS professionals should have a basic understanding of the types of mechanical hazards associated with machinery and the typical risk controls that would be expected. The OHS professional should be able to engage with engineers and, in some cases, ergonomists in assessing the risk of plant and developing suitable control measures. As part of this process, the OHS professional should be able to recognise the potential for safeguarding systems to be defeated or compromised, and be familiar with the means by which such actions can be eliminated or minimised.

8 Summary

All industry and nearly all workplaces rely on óplantô in some form, whether it be the more hazardous machinery such as cutting/sawing, crushing /pressing machinery or conveyors or powered equipment and tools which are usually perceived as less hazardous, but still result in significant injury and even death.

An understanding of the nature of kinetic and potential energy, together with the factors that impact on the machine-human interface are important in assessing risk associated with plant as well as identifying how safeguards may be defeated, bypassed or break down.

Control of plant-related hazard should be achieved through a primary focus on design ï of the plant itself and of guarding as an integral part of the plant ï supported by administrative controls of testing plant condition, Permit To Work and lockout/tagout systems together with information, instruction, training and supervision.

Key thinkers and resources

The Energy Damage Model as described by Viner (1991) is useful for conceptualising how machinery hazards may damage people.

The primary source of information for the generalist OHS professional is the Australian Standards *AS 4024 Safety of Machinery* series (SA, 2006). This provides the framework, terminology and detail necessary for the identification and control of machinery hazards relevant to current Australian requirements. It follows closely the terminology and requirements of European and other international standards for safety of machinery, providing a distinct advantage for OHS professionals working with international organisations or purchasing machinery from overseas suppliers.

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