Mechanical Plant

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OHS Body of Knowledge

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The Manager, OHS Body of Knowledge
Australian Institute of Health & Safety, PO Box 2078, Gladstone Park, Victoria, Australia, 3043
Manager@ohsbok.org.au

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Author

Tony Payne, Director, Payne Consulting Services, Pty Ltd

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Authors

Roger Lim, Principal Consulting Engineer, Plant Safety Solutions Pty Ltd

Tony Payne, Director, Payne Consulting Services, Pty Ltd

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Mechanical Plant

Roger Lim MIEAust CPEng NER APEC Engineer IntPE(Aus) COHSProf

Principal Consulting Engineer, Plant Safety Solutions Pty Ltd

Email: rlim@riskplant.com

Roger is a highly experienced engineer with post graduate qualification in robotics. With over 15 years' experience as a Senior Engineer in Plant Safety with the Victorian WorkCover Authority and its predecessors, Roger has been working in the private industry consulting in plant safety for over 20 years, specialising in machine safety. He represents Engineers Australia in AS4024 machine safety committee. Roger often appears as an expert witness in courts for accident investigations involving mechanical plant and safety of control systems.

Tony Payne BE(Mech), GDipOHM, GDipErg, CPE

Ergonomics Engineer

Director, Payne Consulting Services Pty Ltd

Email: riskybiz@netspace.net.au

Tony is a safety and ergonomics professional with over 30 years' experience working as an employee, researcher and independent consultant. He continues to be one of the Human Factors and Ergonomics Society of Australia representatives on the Standards Australia Committee SF-041 developing the standards on machine safety. He continues to provide consulting services and training to organisations in both the Government and private sectors.

Mechanical Plant

Abstract

Machinery, equipment, appliances or powered 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 guarding 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 controls for mechanical plant, generalist Occupational Health and Safety (OHS) professionals must remain aware of the ways such protections can be defeated or break down. Ensuring safety of mechanical plant has become more complex with technological developments including automation and artificial intelligence and OHS professionals need to be able to engage with engineers, ergonomists and other technical experts.

Keywords

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

Contextual reading

Readers should refer to 1 *Preliminaries* for a full list of chapters and authors and a synopsis of the OHS Body of Knowledge. Chapter 2, *Introduction* describes the background and development process while Chapter 3, *The OHS Professional* provides a context by describing the role and professional environment.

Terminology

Depending on the jurisdiction and the organisation, Australian terminology refers to 'Occupational Health and Safety' (OHS), 'Occupational Safety and Health (OSH) or 'Work Health and Safety' (WHS). In line with international practice this publication uses OHS with the exception of specific reference to the Work Health and Safety (WHS) Act and related legislation.

Jurisdictional application

This chapter includes a short section referring to the Australian model work health and safety legislation. This is in line with the Australian national application of the *OHS Body of Knowledge*. Readers working in other legal jurisdictions should consider these references as examples and refer to the relevant legislation in their jurisdiction of operation.

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1 Introduction

Plant – defined in the national model *Work Health and Safety Act* (WHSA s 4) as "any machinery, equipment, appliance, container, implement and tool" – is a part of nearly all workplaces (SWA, 2016). 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)
- Explosive-powered tools
- Turbines
- Amusement structures.

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 machinery and fixed plant, as well as powered equipment and tools, 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 – including electrical, hydraulic, pneumatic, acoustic energy (noise and vibration); 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 – 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 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 often.

More recent developments in automation, including robotics and artificial intelligence, has attempted to reduce the direct exposure of people to machinery hazards. However it has also increased both the complexity of systems associated with machinery and the complexity of controls for machinery hazards.

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 safeguarding 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[1] 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 hazards.

In 1992 an interim Australian Standard AS 4024.1(Int) was published on safeguarding of machinery. This was based on the British Code of Practice for Safety of machinery BS5304:1988. AS4024.1(Int)-1992 has now evolved to become AS/NZS 4024 *Safety of machinery series (SA/SNZ 2019a)* by adopting a number of ISO/IEC/EN Standards for providing guidance in safety of machinery. This text adoption of international standards

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[1] See *OHS BoK* 9.2 WHS Law in Australia.

enables AS/NZS 4024 to be more dynamic in keeping up with technological changes occurring as a result of increasing automation.

3 Extent of the problem

In 2018 there were 144 traumatic deaths among Australian workers, 17 of these deaths were attributed to 'Machinery & (mainly) fixed plant' with a further 4 workers dying when working with powered equipment tools and appliances. Thus 15% percent of traumatic workplace fatalities were associated with machinery, plant or powered equipment. (Table 1). The predominant mechanism[2] of injury was 'being hit by a moving object'. (Table 2.)

Table 1: Traumatic fatalities associated with machinery, plant and powered equipment, 2018 (SWA, 2019a; p. 23)

	No of fatalities		% of all fatalities	
Agency[3]	2018	5 yr average	2018	5 yr average
Machinery & (mainly) fixed plant	17	17	12%	8%
Powered equipment, tools and appliances	4	4	3%	2%
Total fatalities for machinery, plant and powered equipment	21		15%	

Table 2: Traumatic fatalities associated with machinery, plant and powered equipment with mechanism of injury being 'hit by a moving object', 2014-2018 (SWA, 2019a; p. 24)

Agency	2014	2015	2016	2017	2018	% of 2018 fatalities for agency
Machinery & (mainly) fixed plant	1	3	2	4	2	12%
Powered equipment, tools and appliances	..	3	2	3	1	25%
Total fatalities for machinery, plant and powered equipment and being hit by a moving object	1	6	4	7	3	63%

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2 "The mechanism of injury or disease classification is used to describe the action, exposure or event that was the direct cause of the most serious injury or disease." (SWA, 2020; p. 21)

3 'Agency' "identifies the object, substance or circumstance principally involved at the point at which things started to go wrong and which ultimately led to the most serious injury or disease". (SWA, 2020; p. 22.)

In addition to those workers who died when working with machinery, plant or powered equipment, national workers' compensation claims data (SWA, 2020) indicate that for the year 2017–18 a total of 9645 claims (9% of all claims) related to use of machinery (mainly fixed plant) and powered equipment, tools and appliances. (Table 3.)

For claims associated with machinery and fixed plant, the most frequent mechanisms were being hit by a moving object (36% of claims for machinery and fixed plant); and hitting objects with part of the body (14% of claims for machinery and fixed plant). Heat, electricity and other environmental factors accounted for 4% of claims associated with machinery and fixed plant in 2017-18. (Table 3.)

Table 3: Number of claims for machinery, plant and powered equipment 2017-18 (SWA, 2020)

Agency	Mechanism	No of claims	% of all claims	No of claims	% of claims for agency
Machinery & (mainly) fixed plant	All	5095	5%		
	Being hit by moving object (kinetic energy)			1825	36%
	Hitting objects with part of the body (kinetic energy)			730	14%
	Heat, electricity and other environmental factors			210	4%
Powered equipment, tools and appliances	All	4550	4%		
Total claims for machinery, plant and powered equipment		9645	9%		

While the numbers are small (statistically), the trend data shows a consistent decline in traumatic fatalities associated with machinery and fixed plant between 2013 and 2017 but an increase in 2018. While there was some decline in deaths associated with powered equipment and tools between 2003 and 2014 this improvement has not been maintained. (Table 4 and Figure 1.)

Table 4: Trend data for traumatic fatalities associated with machinery, plant and powered equipment 2003 – 2018 (SWA, 2018, 2019a)

Agency	2003	2012	2013	2014	2015	2016	2017	2018
Machinery & (mainly) fixed plant	23	23	24	21	18	14	13	17
Powered equipment, tools and appliances	8	6	4	2	6	3	4	4
Total fatalities for machinery, plant and powered equipment	31	29	28	23	24	17	17	21
% of all fatalities	12%	13%	14%	12%	11%	9%	9%	15%

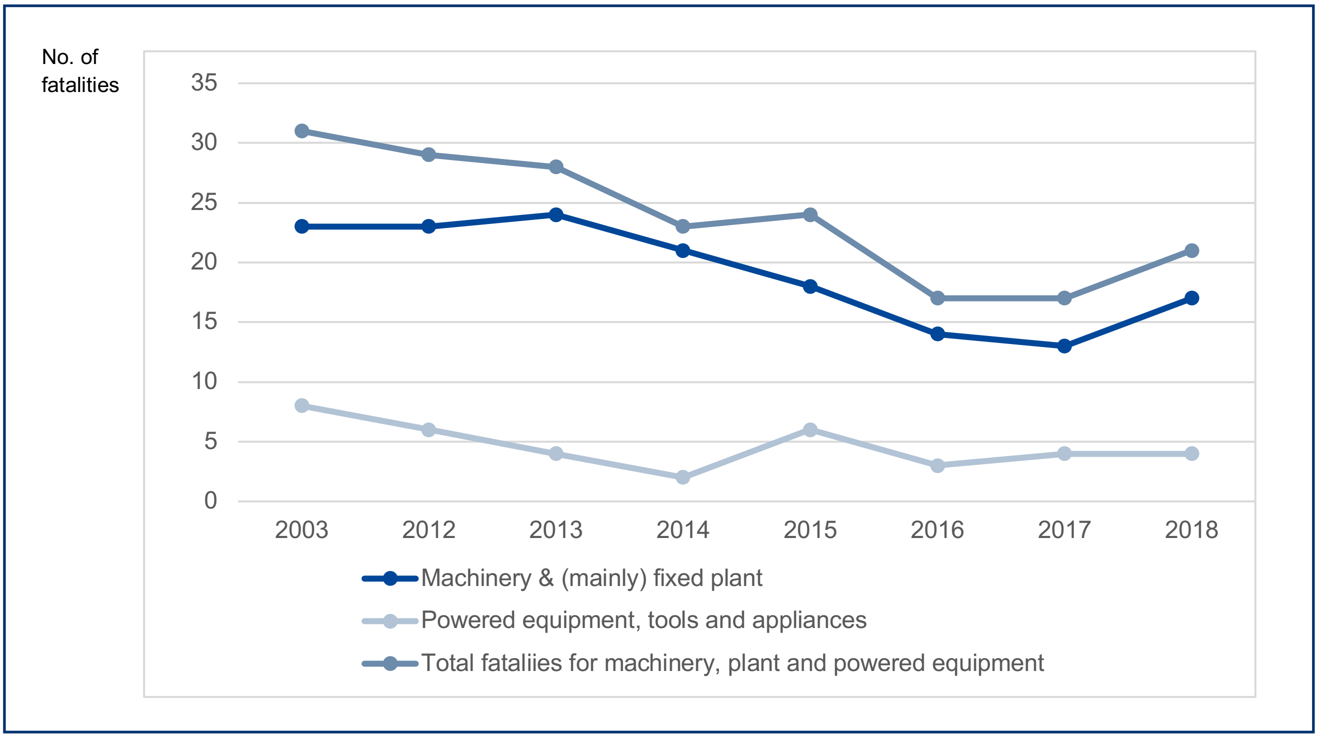

Figure 1: Trend in traumatic fatalities associated with machinery, plant and powered equipment, 2003-2018

Trend data for claims associated with machinery plant and powered equipment shows a significant reduction between 2000 and 2012. While there was a small decrease in claim numbers between 2012 and 2014, the number of claims per year has remained static since 2014. (Table 5 and Figure 2.)

Table 5: Trend in number of claims for machinery, plant and powered equipment 2000-2018 (SWA, 2020)

Agency	2000-01	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
Machinery & (mainly) fixed plant	9,295	5,725	5,480	5,110	5,010	5110	5095
Powered equipment, tools and appliances	6,375	5,480	4,970	4,860	4,595	4550	4550
Total claims for machinery, plant and powered equipment	15,670	11,205	10,450	9,970	9,605	9660	9645
% of all claims	12%	10%	9%	9%	9%	9%	9%

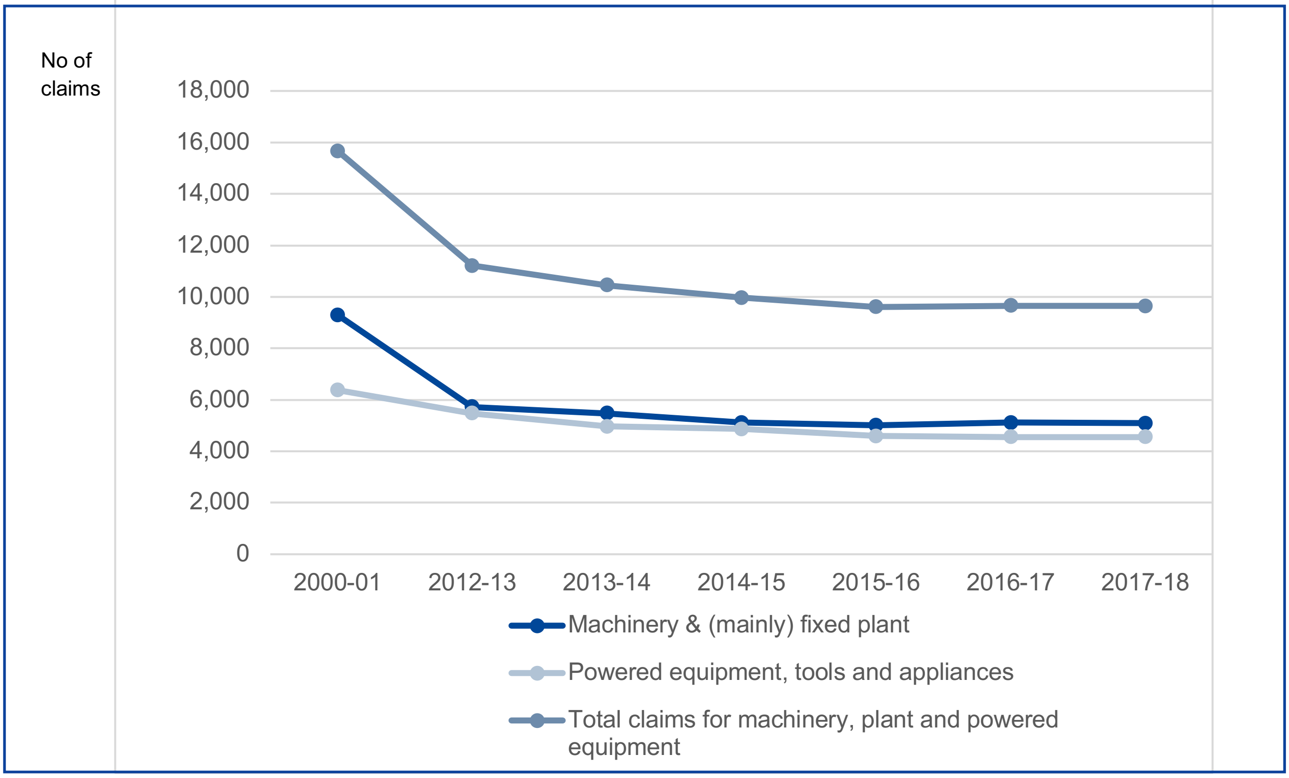

Figure 2: Trend in workers' compensation claims associated with machinery, plant and powered equipment, 2000-2018

Overall, this data shows that machinery, plant and powered tools and equipment continue to be a major contributor to fatalities and injury in Australian workplaces and there has been little improvement in the last five years.

4 Understanding plant hazards

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

> *Kinetic energy hazards* involve "things in motion" and "impact," 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.[4]
>
> *Potential energy hazards* involve "stored energy." 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 "susceptible to sudden unexpected movement." 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, n.d.)

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 the 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; 2015)[5] provides a framework for understanding the hazards associated with machinery in terms of the energy sources within the system.[6] 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,[7] 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).

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[4] Being 'hit by moving objects' and 'hitting objects with part of the body' (see s 3) are examples of kinetic energy.

[5] See also OHS *BoK* 32 Models of Causation: Safety.

[6] See OHS *BoK* 15 Hazard as a Concept

[7] See OHS *BoK* 23.1 Electricity.

Electrical energy may be transformed into forms of energy other than kinetic energy. For example, it may be transformed into potential energy – represented by stored pressure of gases or liquids as in pneumatic and hydraulic systems, or by stored energy in machine components such as springs – 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 may include:

- Acoustic energy (noise[8] and vibration[9])
- Electrical energy[10]
- Chemical energy associated with chemicals used to operate and maintain machinery and from emissions[11]
- Thermal energy from fuels[12] or friction
- Ionising[13] or non-ionising radiation[14]
- Human energy required for posture, movement and operation of machinery.[15]

4.2 Injury process and outcomes

In line with Viner's (1991, 2015) Energy Damage Model, hazards will cause an injury when the intensity of energy transferred to a person exceeds the threshold of the person's 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/NZS 4024.1201:2014 Safety of Machinery – General Principles for design – Risk assessment and risk reduction (SA/SNZ 2014a)* and *AS/NZS 4024.1303:2014 Safety of Machinery – Risk Assessment – Practical guidance and examples of methods* (SA/SNZ, 2014b) 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

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[8] See *OHS BoK* 22.1 Occupational Noise.

[9] See *OHS BoK* 22.2 Vibration.

[10] See *OHS BOK* 23.1 Electricity.

[11] See *OHS BoK* 17.1 Chemical Hazards.

[12] See *OHS BoK* 17.4 Process Hazards (Chemical).

[13] See *OHS BoK* 24 Ionising Radiation.

[14] See *OHS BoK* 25 Non-Ionising Radiation.

[15] See *OHS BoK* 16 Musculo-Skeletal Disorders.

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.

As noted in section 4.1, energies other than kinetic and potential energy are associated with mechanical plant and may result in a range of injury outcomes such as:

- Hearing loss over time
- Musculo-skeletal impacts of vibration
- Electrical shock and burns
- Inhalation of mists, fumes and dust
- Fire or explosion
- Burns and exposure to heat or cold
- Slips, trips and falls
- Musculo-Skeletal Disorders (MSDs) from musculo-skeletal stress associated with operating machinery and equipment.

Annex B of AS/NZS 4024.1204:2019 *Safety of Machinery – Electrical equipment of machines – General requirements* (SA/SNZ, 2019b) provides examples of hazards, hazardous situations and hazardous events.

4.3 Risk factors

Examples of contributory risk factors for mechanical hazards associated with plant include:

- *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)
- *Mechanical strength:* which when inadequate 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/NZS 4204.1601:2014 *Safety of machinery - Design of controls, interlocks and guarding – Guards – General requirements for the design and construction of fixed and moveable guards* (SA/NZS, 2014c) 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 4343–2014 Pressure Equipment – Hazard Levels* (SA, 2014) 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.

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 routine 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 The impact of technology

With increasing automation of machinery, introduction of 'smart' devices with software and hardware integration and artificial intelligence (AI) built into machinery[16], the safety integrity of the machine controls must be assessed when these machines interact with humans. (See section 6.2 for discussion on the safety of engineering control systems).

Industrial robots are commonly used in manufacturing machines with automated guided vehicles (AGVs) increasingly being used to replace manual forklift trucks particularly in warehousing environments. The development of robots that interact directly with humans (collaborative robots or 'cobots') has brought about the need for higher levels of safety controls which may include:

- Safety monitored stop where the robot stops when a human enters the work envelope
- Speed and separation control where the more advanced systems slow the operation

[16] Collectively, such technology is often referred to as *Industry 4.0* reflecting the concept of the 4th Industrial Revolution. The first industrial revolution being mechanisation through water and steam power, the second – mass production and assembly lines, the third brought about by computers and automation. (See Marr, 2018.)

when a human worker approaches then stops the operation should a worker get too close

- Power and force limiting robots usually have rounded corners and intelligent collision sensors to detect a human worker and cease operation
- Hand-guided devices where an operator directly controls the robot. (RIA, 2019)

Standards relevant to safety related to robots are:

AS 4024.3301:2017 *Safety of Machinery: Robots and robotic devices – Safety requirements for industrial robots – Robots* (SA, 2017a) *(*adopted from ISO 10218-1:2011)

AS4024.3302:2017 *Safety of Machinery: Robots and robotic devices – Safety requirements for industrial robots – Robot systems and integration* (SA, 2017b) (adopted from ISO 10218-2:2011)

AS 4024.3303:2017 *Safety of Machinery – Robots and robotic devices – Collaborative robots* (SA, 2017c)(adopted from ISO 15066:2016.

4.6 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/NZS 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 9486 people who were injured or killed in 2018 as a result of working with machinery, plant or powered equipment.

5 Legislation and standards

5.1 Legislation

The national model *Work Health and Safety Act* (WHSA ss 21–26) (SWA, 2016) and the model Work Health and Safety Regulations (WHSR ss 187–202) (SWA, 2019b) 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). These obligations specifically refer to the "safe, use, handling and storage of plant" (WHSA s 19(3)(d)).

In addition to providing detail on the general obligations of designers, manufacturers, installers and others, the model regulations place additional obligations on PCBUs regarding management of risk associated with plant including installation and commissioning as well as normal operation. These requirements address:

- Prevention of unauthorised alteration or interference with plant
- Proper use of plant
- Plant not in use
- Guarding
- Operational controls, emergency stops and warning devices
- Maintenance and inspection. (WHSR, ss 203-213) (SWA, 2019b)

The Regulations also specify requirements for worker protection around industrial robots (s 222) and inspection of pressure equipment (s 224).

5.2 Standards

An extensive range of national and international standards have been developed to support the assessment and control of mechanical hazards related to machinery. As part of international conformity, the standards associations of Australia and New Zealand have, in most cases, adopted existing ISO/EC/EN standards. The current Australian/New Zealand standards on plant safety are referred to as AS/NZS 4024.1-2019 series *Safety of Machinery (SA/SNZ, 2019a)*. This comprehensive series of more than 25 standards is designed to:

> enable those who design, manufacture, supply, control, use and maintain machinery to minimize the risks to the health and safety of people working with or near machinery by providing technical principles for the design, manufacture, maintenance and use of machine systems. (SA, 2019b), p. 1)

The standards most relevant to the generalist OHS professional are listed at the end of the chapter.

6 Control of 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 the less reliable but still important, administrative controls, such as testing of the condition of plant, systems of work including provision of information, instruction and training, Permit to Work systems and appropriate supervision.

6.1 Elimination or minimisation through design

Opportunities to control plant hazards begin at the design stage. Where reasonably practicable, the hazard should be eliminated, such as designing a pop-out roller of conveyor to eliminate pinching of the hand. If this is not reasonably practicable, the use of low-speed, low-pressure or low-energy components may reduce risks 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. Alternatively, the moving part or parts should be wide enough to prevent crushing of the different parts of the body.[17]

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[17] See *OHS BoK* 34.2 Introduction to User-Centred Safe Design and *OHS BoK* 34.3 Health and Safety in Design for information on the influencing the design process and a tool to facilitate engagement in the design process by OHS professionals.

The importance of design in safety of plant is reflected in the number of relevant standards with 'design' in the title (see section 5.2). Three key standards addressing design to prevent entrapment and crushing are:

AS/NZS 4024.1703:2014 *Safety of machinery – Human body measurements – Principles for determining dimensions required for access openings.* (SA/SNZ, 2014d)

AS/NZS 4024.1801:2014 *Safety of machinery – Safety distances to prevent danger zones being reached by upper and lower limbs.* (SA/SNZ, 2014e)

AS/NZS 4024.1803:2019 *Safety of machinery – Safety distances and safety gaps – Minimum gaps to prevent crushing of parts of the human body.* (SA/SNZ, 2014f)

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. This expectation is reflected in the national model legislation which requires that for certain types of plant the design must be registered 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) (WHSR s 243-244) (SWA, 2019b).

6.2 Engineering controls: Guarding to prevent or control access

After design, the most common method of risk control for hazards associated with plant is to prevent a person entering the zone where the damaging energy can be transferred to the person. This may be by fixed guarding, or by controlling the damaging energy when a person needs to enter the zone by using interlock guarding or presence sensing systems.

The Model WHS Regulations 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 physical 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. (WHSR s 189) (SWA, 2019b).

AS/NZS 4024.1601 Safety of Machinery – *Design of controls, interlocks and guarding- Guards- General requirements for the design and construction of fixed and movable guards* (SA/SNZ, 2014c) and *AS/NZS 4024.*1602 *Safety of Machinery – Interlocking Devices Associated with Guards – Principles for Design and Selection* (SA/SNZ, 2014g) 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 frequency of access to the hazardous zone provides a guide to the selection between fixed (including permanent fixed) guarding and interlocked including presence-sensing system. These types of guard are discussed below.

6.2.1 Fixed guards

Fixed (including permanently fixed) guards are usually suitable where the frequency of access is low, such as for maintenance access following isolation lock-out tag-out (LOTO) of energy sources.

The effectiveness of guarding to prevent access to hazardous zones relies on the application of a 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 of Machinery - Safety Distances to Prevent Danger Zones Being Reached by the Upper and Lower Limbs (SA/SNZ, 2014e)

AS 4024.1803 Safety of Machinery – *Safety Distances and Safety Gaps -Minimum Gaps to Prevent Crushing of Parts of the Human Body* (SA/SNZ, 2019c).

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.

6.2.2 Interlocked guards and presence-sensing systems

Interlocked guards (including presence-sensing systems) are usually suitable where access may be required during operation of the plant where it is not reasonably practicable to apply fixed guarding (e.g. for minor intervention tasks such as loading/unloading process, clearing of minor jams and minor alignment of products).

Two types of interlocks 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 'one size fits all' 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 include:

- *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 'trapped' 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.

For guidance on the type of interlocking and the selection of interlocking devices see:

AS 4024.1602 *Safety of Machinery – Interlocking Devices Associated with Guards – Principles for Design and Selection* (SA/SNZ 2014g).

Protective equipment such as light curtains, pressure mats and laser-scanning devices are becoming more commonly used. Since presence sensing systems are non-physical barriers, an important consideration is the ability of the machine to stop before a person is able to reach the identified hazard. Guidance on the effective positioning of presence-sensing system is provided in:

AS4024.2801:2017 *Safety of machinery – Positioning safe guards with respect to approach speeds of parts of the human body* (SA, 2017d)

AS4024.2802:2017 *Safety of machinery – Application of protective equipment to detect the presence of persons* (SA, 2017e).

Safety related parts of control systems

The Safety Related Parts of Control Systems (SRP/CS) refers to the parts of a control system which responds to input signals (e.g. machine guard interlock switch or emergency stop switch or presence sensing systems) and generates safety-related output signals (e.g. de-energising the machine primary control elements such as contactors to stop the relevant parts of the machine). This also includes monitoring systems.

SRP/CS are designed based on the level of risk associated with the machine hazard. Estimating the level of risk and designing, testing and proving that the SRP/CS meets the required level of reliability is an advanced engineering function. Guidance for this design and testing (also referred to as functional safety) are set out in:

AS/NZS 4024.1501-2006 (R2014) *Safety of Machinery – Design of Safety-related Parts of Control Systems – General Principles for Design* (SA/SNZ, 2014h), and

AS/NZS 4024.1502-2006 (R2014) *Safety of Machinery - Design of Safety-related Parts of Control Systems – Validation)* (SA/SNZ, 2014i).

In Australia, the use of categories of SRP/CS is becoming more widely understood and there will be a transition period to allow engineers time to work with and understand the probabilistic approach described in AS/NZS 4024.1503 and AS 62061. It is envisaged that on completion of work by the international standards committee (including Australian Standards committee participation), combining ISO 13849-1:2006 and IEC 62061, the resulting unified standard will replace both AS 4024.1501 and AS/NZS 4024.1503.

An alternative to the Category of the Safety Related Parts of Control System (SRP/CS) is the Performance Level. These levels require a determination of the probability of dangerous failure, and this is considered to be a more comprehensive indicator of functional safety. See:

AS4024.1503 Machinery Safety - *Safety-related Part of Control Systems – General Principles for Design (SA/SNZ, 2014j)*.

SRP/CS using complex electronics such as safety Programmable Logic Controllers (PLCs) will require an assessment of the Safety Integrity Level (SIL) using:

AS 6206:2019 *Safety of Machinery – Functional Safety of Safety-related Electrical, Electronic and Programmable Electronic Control Systems (SA, 2019a)*.

The design and validation of the safety systems are complex and this complexity is increasing with greater reliance on automation and artificial intelligence (AI). OHS professionals should engage with safety engineers to carry out the risk assessment and ensure the safety engineer carries out validation, including test results of the safety functions, especially where automated systems interface with humans.

6.3 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 for major intervention access such as maintenance work , or by activation of the SRP/CS for minor intervention access such as clearing of minor jammed parts.

6.3.1 Energy isolation

Isolation is usually required for major intervention access such as maintenance work or clearing of major jams. In such cases, isolation of energy sources and dissipation or containment of stored energy is required to prevent hazards arising whilst personnel are in the hazard zone. Energy isolation is usually an integral part of a Permit To Work system including Lockout/tagout (section 6.4.2). For guidance see:

> AS/NZS 4024.1603 *Safety of Machinery – Design of controls, interlocks and guards – Prevention of Unexpected Start-up* (SA/SNZ, 2019d).

Note that interlock guard switches, presence sensing systems and emergency stop switches are normally suitable for minor intervention access, usually by the operator during routine operation, but should not be used in place of energy isolation, lockout/ tagout (LOTO) systems which are required for major intervention access such as maintenance works.

Examples of **minor intervention** tasks for low frequency exposures include:

- Clearing of minor jams
- Re-adjustment or re-alignment of parts
- Minor surface cleaning
- Single loading or unloading of parts, etc.

The levels and types of minor intervention access applicable would depend on the level of safety integrity of the SRP/CS.

An example of identifying the minor and major intervention access for the plant would be to develop an Energy Isolation Guide (EIG) shown in Figure 3.

PLANTSAFETY SOLUTIONS PTY LTD

SAMPLE

ENERGY CONTROL & ISOLATION POINTS GUIDE

Rev.No.	Developed By:	Approved By:	Date	DR No.
0				
1				
2				
3				

Plant Description:	**Palletiser**
Location:	Packing Hall

Total number of isolation points: 3

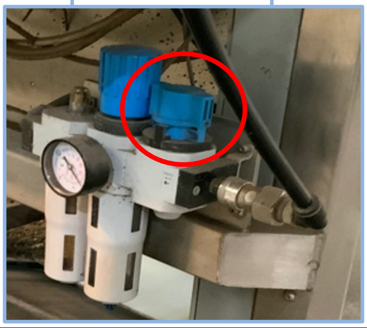
Category of Control System: Cat.3 / PL_d

CAUTION

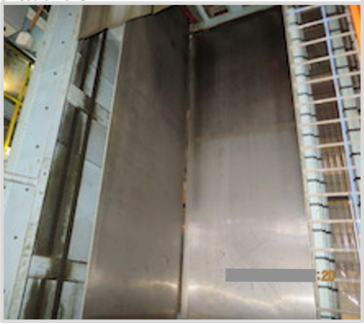
Mechanical restraint required before access under raised hoist.

Electrical Control Cabinet
Main Electrical Isolator
E-1

Pneumatic Isolator
P-1



Gravitational energy under raised hoist
Fit clear labelling requiring use of mechanical restraint. G-1



ALWAYS SHUT DOWN THE MACHINE BEFORE ENERGY ISOLATION AND LOCKOUT

ID	Source	Device	Location	Lock Out Method &/or Releasing Energy	Check Procedure
E - 1	ELECTRICAL	Padlock	Located on the front of the main electrical cabinet next to the operator control panel.	Turn isolating switch to OFF Apply tag & personal padlock. If possible ensure production data is collected before switching machine off	Power Indicator Light on Main Control Verify machine will not start from controls
P - 1	PNEUMATIC - AIR	Padlock	Located on the eastern side next to the empy pallet hoist.	Turn isolating valve to CLOSED and release any trapped air Apply tag & personal padlock.	Observe pressure gauge reads zero and attempt to operate the manual product push arm. Confirm the push arm does not operate.
G - 1	GRAVITY	Mechanical bars	Fit labels to identify storage of bars and location to insert bars.	Insert mechanical support.	Observe mechanical pins position switch indicating light is illuminated.

DANGER

<< any other safety message here>>

Safety is Your Responsibility

DANGER

LOTO EXCEMPTION (Allowed Minor Interventions for Cat.3 / PL_d control system)

Exceptions of LOTO are permitted when accessing through interlocked gates and light guards when:

- Clearing of minor jams (less than 10 minutes)
- Minor adjustments
- Spot cleaning of electronic eyes of other sensors
- Straightening products
- Minor surface cleaning (excludes cleaning under machine)

IF IN DOUBT, LOCK IT OUT

Figure 3: Example of energy isolation guide

6.3.2 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
- *Emergency stops*, are manually operated devices intended to avert harm or reduce damage to persons, machinery, or work in progress by stopping a machine in an immediately hazardous situation.

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

6.4 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 model WHS regulations (SWA, 2019b) place particular emphasis on the prevention or defeat of safeguarding systems by requiring the designer to ensure guarding is “designed to make by-passing or disabling of the guarding, whether deliberately or by accident, as difficult as is reasonably possible” (WHSR s 189 (4)). The PCBU has a similar duty (WHSR s 208 (3)). There is also an obligation on the PCBU to “ensure that measures are implemented to prevent alterations or interference with the plant that are not authorised by that person” (WHSR s 205).

In addition the machinery safety series of standards AS/NZS 4024.1 (SA/NZS, 2019a) 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. The safeguarding system must therefore be designed to be efficient in recovery as a cumbersome safeguarding system will lead to an incentive to defeat or circumvent the protective measures.

The importance of well-designed guarding and establishment and maintenance of systems to ensure their integrity is reflected in the number of injuries and prosecutions resulting from the breakdown of such systems. The examples below are drawn from the prosecution summaries published by just one jurisdiction (Victoria) over a three month period (September to December) 2019. (WorkSafe Victoria, 2019)

Unguarded rollers on a paper mill

The offender operates a business that includes the production and printing of lithographic and corrugated cardboard packaging cartons and products.

A large item of plant, known as the paper mill, was being commissioned for use at the workplace and had been in testing for approximately 3 to 5 months.

Situated in the paper winding area of the paper mill were two steel rollers. Bodily access could be gained to a nip point between the two steel rollers, creating a risk of serious injury by entanglement, entrapment or crushing.

It was reasonably practicable for the offender to eliminate or reduce the risk by isolating the plant from people using engineering controls to eliminate or reduce bodily access to the nip point. Such engineering controls could include perimeter fencing for large areas where access was needed by authorised employees.

On 7 March 2016 the paper mill was being run for the first time. An employee of the offender was assisting with the paper mill in the paper winding area when his hand was dragged into the nip point. He sustained serious crush injuries to his hand.

Approximately one to two hours later the paper mill was being run again. An experienced paper maker, a person other than an employee, was voluntarily assisting set up the paper mill. He was in the paper winding area feeding paper through the nip point when his left glove was caught in between the two moving rollers and his glove and hand was pulled in, crushing his fingers and causing serious injury.

Unguarded rollers on flat iron machine

The workplace is a large commercial laundry. A flat iron worker and employee of the offender was working with her supervisor feeding clothing items onto the conveyer and front feeder area of a flat iron machine. The cord of a hospital gown became entangled in the roller and dragged her into the machine trapping her arm and shoulder between the roller and feeding plate of the iron. A crow bar was used to prise open the feeder plate to allow the employee's arm to be released.

On a previous occasion at the same workplace another employee was working on the same machine and was injured when a gown string became entangled around the roller. The company took measures to eliminate the risk of crush or entanglement by fitting a guard to the danger areas such as the in running nip points. However some months before the current incident the company removed the guard when employees complained that working on the machine caused back pain. It was not replaced with another, improved, or differently engineered guard. This caused a risk of serious injury to employees using the ironing machine without the guarding.

The risk eventuated when an employee suffered crush injuries to her right arm and shoulder, third degree burns requiring a skin draft from her thigh and ongoing anxiety.

Ineffective guard and unsafe system of work

('The offender') designed and manufactured steel castings and supplied its products to mining and industrial companies worldwide.

Part of the business involved using an item of plant known as a paddle mixer. The paddle mixer was used to mix a powder called 'magcast' with water. 200 kilograms of magcast and water would be placed in the paddler mixer and a four bladed auger mixed it together. Once mixed, a hinged steel gate would be opened by hand and the mixture would flow down a guarded chute into a hopper/wheelbarrow to be carted away.

It was not uncommon for blockages to occur in the chute during the task. Employees were trained to close the hinged steel gate and use a metal bar to loosen the mixture, before opening the steel gate again to continue. The guard was in poor condition. The offender failed to maintain a system of work to ensure that there was a standard operating procedure in place for the cleaning of blockages in the chute of the paddle mixer, thereby exposing its employees to risks to health and safety ("the risk").

On 1 July 2018, the risk eventuated when the injured worker was performing the task when a blockage occurred in the chute. The injured worker put his hand in a gap in the guard to loosen the mixture and two of his fingers came into contact with the auger causing shearing injuries to the tips of those fingers. He was taken to hospital and underwent successful surgery to reattach the tips to his fingers.

WorkSafe inspectors attended shortly after the incident and issued a prohibition notice concerning the plant. Later that day, WorkSafe inspectors re-attended the workplace and observed a new guard had been designed, manufactured and installed on the chute.

Inadequate guarding of beam saw

('The offender') manufactures industrial products. The injured person was employed by the offender as a Supervisor and Operator and had worked at the offender for the past 22 years.

The injured person's duties included operation of a beam saw at the workplace. The beam saw is a computer numerically controlled item of plant, which is used to cut various non-metallic products, including switch panels made from compressed paper. The beam saw automatically feeds product from the rear, cuts it and pushes the final product to the front. The operator then takes the final product from the machine and places it on a table or pallet nearby.

The beam saw blade is mounted on a carrier and is fully enclosed by a steel guard and is located beneath the machine. The machine automatically raises the blade and performs one cut, then the blade retracts. The blade is driven via a v-belt and pulley.

The process of cutting switch panels produces small offcuts approximately 6mm wide and between 500mm and 1220mm long. These offcuts are small enough to fall into the gap between the blade and the saw bed and land inside the machine. After approximately 50 cuts, the offcuts would regularly build up inside the machine to such an extent that the blade carrier would jam and the saw would cease to function.

When a jam occurred, the operator would turn off the machine, open the two front guards and remove the offcuts.

On 10 April 2018, the injured person was tasked to cut switch panels. On that day, he had removed the front left guard to observe the falling offcuts, with the intention of designing a deflection system so that the falling offcuts did not obstruct the saw blade carrier. The front guards were not fitted with interlocks or other means of shutting down the machine when the guards were opened, meaning that the machine could still be operated with the front guards removed.

Whilst watching the machine in operation, an offcut fell onto the airlines. The injured person pressed the stop button on the machine control panel and put his hand into the machine to remove the offcut. Pressing the stop button on the machine stops the saw blade from traversing along the machine, but there is a run-down time of approximately 45 seconds for the v-belt. As he pulled the offcut out, his fingers got caught in the v-belt and pulley, causing a laceration injury to those fingers.

Inadequate guarding and unsafe system of work

The offender is a leading manufacturer of standard and custom designed caps and closures.

The workplace contains a number of automatic wadding machines (plant) which are used to insert different sizes of plastic caps in induction sealing wads. The plant worked by feeding caps into the wad press down area. The wad press down area consists of a central plunger that forces the wadding into the top of the caps.

The plant was fitted with safety doors which were not interlocked; this meant that the safety doors could be opened and employees could gain bodily access to the danger area of the plant while it was online, creating a risk of serious injury by stamping, crushing or cutting. The offender had trained its employees in a system of work that required activation of the emergency stop button if for any reason they required access to the wad press down area.

On 13 April 2018, an employee accessed the wad press down area to remove built up wadding which had become jammed. At the time the machine appeared to be stationary, so the employee proceeded to open the safety doors, forgetting that the machine was online. As she was clearing the built up wadding, the central plunger regained motion and crushed the tip of her right index finger. The offender failed, so far as was reasonably practicable, to eliminate the risk to employees by ensuring that the safety doors were interlocked to prevent access to the danger area while the plant was in operation.

6.5 Administrative controls

Considering the potential severity of injuries associated with mechanical plant, risk control efforts should focus on good design and the use of guarding or machine controls. However, there will be residual risk and, while less reliable than higher level prevention, administrative controls are an essential part of the ‘package’ for control of plant-related hazards. Such controls include procedural activities of testing and isolation, permit-to-work and lockout/tagout processes as well as information, instruction, training and supervision.

6.5.1 Testing

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 model regulations (WHSR s 224) and

AS/NZS 3788 Pressure Equipment – In-service Inspection-2006 (2017) (SA/SNZ, 2017). 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.

6.5.2 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 guarding. The types of administrative controls commonly found in industry include Permit To Work and lockout/tagout (LOTO). 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 and non-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 (section 6.3.1). These are commonly referred to as Lock Out/Tag Out systems (LOTO). In all LOTO processes there is personal responsibility given to the person(s) undertaking the work to comply with the isolation and tagging process. Some systems simply involve tagging out isolators or controls (without locks) prior to accessing the machinery. This is less effective and open to breaching of the isolation and potentially exposing workers to damaging energies.

6.5.3 Information, instruction, training and supervision

Provision of information, instruction, training and supervision is an important strategy in controlling the risk associated with plant. Under the model Work Health and Safety Act (SWA, 2016) there is a general duty to provide information, instruction, training and supervision for workers (WHSA s 19.2(f)). The model Act includes specific requirements for designers, manufacturers, importers and suppliers to, on request, provide appropriate information on plant (WHSA ss 22(4), (5); 23(4), (5); 24(4), (5); 25(4), (5)). These obligations are mirrored in the model Regulations for plant (WHSR ss 187, 195, 196, 198).

Even when 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.

Information provided to workers should include standard operating procedures as appropriate.[18] [19]

6.6 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. PPE generally does not provide protection 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. However, whilst being the lowest order control option, the wearing of safety footwear and suitable clothing can assist in reducing the likely consequences of contact with moving machinery or machine components.

7 Implications for OHS practice

Recognition and control of mechanical hazards is relevant to all industries using machinery. While agriculture, mining, processing, construction, manufacturing, food, retail and logistics are obvious users of machinery, mechanical hazards are evident in many other industries (e.g. 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

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[18] See *OHS BoK* 12.3 Rules and Procedures for a review of current research on the role of rules and procedures in control of OHS risk.

[19] See *OHS Bok* 12.4 Documentation Usability (in development at time of writing).

safeguarding systems to be defeated or compromised, and be familiar with the means by which such actions can be eliminated or minimised.

OHS professionals should recognise when specialist expertise is required (e.g. for hazards associated with stored energy especially hydraulic and pneumatic systems and where technology may impact on the hazards and their control). The evolution in machine guarding includes advancements in monitoring of safety switches, sensors and similar devices by use of safety relays and safety PLCs in the safety circuits of machine control systems. These functional safety systems add complexity and generalist OHS professionals should work with specialist safety systems experts and engineers who may provide the appropriate safety validations for the OHS generalists to assist in the management of risks.

While the complexity created by technology may require engineering expertise in the assessment and control of mechanical hazards, generalist OHS professionals have an important role. Their input should ensure that:

- Plant design and control systems, including procedures, are appropriately designed for the purpose of the machine
- Design takes account of input by those familiar with the use of the plant.

OHS professionals will also be aware that cumbersome systems of work and safety management systems can lead to incentives to circumvent or defeat machine safety controls and these issues should be considered in design and implementation of such systems.

Furthermore the generalist OHS professional can play an important role in the purchasing process for new machinery. Through the recognition and inclusion of the relevant legislation and international and Australian standards in the purchasing specifications for imported or locally sourced machinery, the OHS professional can positively influence the level of safety of machinery arriving at workplaces. This involvement can also provide significant benefits to the organisation in reducing the need to retrofit and upgrade new machinery to meet local standards and legislation.

8 Summary

All industry and nearly all workplaces rely on ‘plant’ 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 hazards should be achieved through a primary focus on design – of the plant itself and of guarding as an integral part of the plant – supported by administrative controls of testing plant condition, Permit To Work and lockout/tagout systems together with information, instruction, training and supervision.

Whilst some aspects of plant safety require engineering expertise, generalist OHS professionals have an important role in plant safety and should work with engineering and production personnel as well as operators to ensure the hierarchy of controls is applied to the safety of plant.

Key thinkers and resources

The Energy Damage Model as described by Viner (1991, 2015) 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. This series of standards 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. Appendix B of AS4024.110:2019 *Safety of Machinery – Application Guide* (SA, 2019b) provides a cross reference against of the standards that have adopted ISO or IEC Standards.

Standards

Those of most relevance to generalist OHS professionals are listed below with references noted for those standards cited in the chapter.

AS4024.1100:2019 Safety of machinery – *Application Guide.*

AS/NZS 4024.1201:2014 *Safety of machinery – General principles for design – Risk assessment and risk reduction.*

AS/NZS 4024.1204:2019 *Safety of machinery – Electrical equipment of machines – General requirements* (IEC 60204-1:2016(ED.6.0)MOD)

AS/NZS 4024.1303:2014 *Safety of machinery – Risk assessment – Practical guidance and examples of methods.*

AS/NZS 4024.1401:2014 *Safety of machinery – Ergonomic principles – Design principles - Terminology and general principles.*

AS/NZS 4024.1501-2006 (R2014) *Safety of machinery – Design of safety related parts of control systems – General principles for design.*

AS/NZS 4024.1502-2006 (R2014) *Safety of machinery – Design of safety related parts of control systems – Validation.*

AS/NZS 4024.1503:2014 *Safety of machinery – Safety related parts of control systems – General principles for design.*

AS/NZS 4024.1601:2014 *Safety of machinery – Design of controls, interlocks and guarding – Guards – General requirements* for design and construction of fixed and movable guards.

AS/NZS 4024.1602:2014 *Safety of machinery – Interlocking devices associated with guards – Principles for design and selection.*

AS/NZS 4024.1603:2019 *Safety of machinery – Design of controls, interlocks and guards- Prevention of unexpected start-up.*

AS/NZS 4024.1604:2019 *Safety of machinery – Design of controls, interlocks and guarding – Emergency stop - Principles for design* (ISO 13850:2017(ED.3.0),MOD)

AS/NZS 4024.1703:2014 *Safety of machinery – Human body measurements – Principles for determining dimensions required for access openings.*

AS/NZS 4024.1801:2014 *Safety of machinery – Safety distances to prevent danger zones being reached by upper and lower limbs.*

AS/NZS 4024.1803:2019 *Safety of machinery – Safety distances and safety gaps – Minimum gaps to prevent crushing of parts of the human body.*

AS 4024.2801:2017 *Safety of machinery – Positioning safe guards with respect to approach speeds of parts of the human body.*

AS 4024.2802:2017 *Safety of machinery – Application of protective equipment to detect the presence of persons.*

AS 4024.3301:2017 *Safety of machinery – Robots and robotic devices – Safety requirements for industrial robots – Robots.*

AS 4024.3302:2017 *Safety of machinery – Robots and robotic devices – Safety requirements for industrial robots – Robot systems and integration*.

AS 4024.3303:2017 *Safety of machinery – Robots and robotic devices – Collaborative robots.*

AS 62061:2019 *Safety of machinery - Safety of Machinery – Functional Safety of Safety-Related Electrical, Electronic and Programmable Electronic Control systems*.

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