Safety Science 75 (2015) 163–173

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Analysis and prevention of serious and fatal accidents related to moving parts of machinery

Yuvin Chinniah *

Department of Mathematics and Industrial Engineering, Polytechnique Montreal, P.O. Box 6079, Station Centre-ville, Montreal, QC H3C 3A7, Canada

ARTICLE INFO

Article history:
Received 21 September 2014
Received in revised form 20 January 2015
Accepted 6 February 2015
Available online 3 March 2015

Keywords:
Safety of machinery
Accidents
Lockout
Safeguarding
Risk assessment
Moving parts of machine

ABSTRACT

Machines contain hazards of different nature and exposure to those hazards can result in injuries or deaths. Safety of machinery considers the ability of a machine to perform its intended function during its life cycle where risk has been adequately reduced. The principles of machine safety, risk assessment and risk reduction are covered in international standards, national standards, regulations and other literature. Moving parts of machinery still cause many serious injuries and fatalities. This paper aims at analyzing serious injuries and fatalities related to moving parts of machinery in order to understand the various reasons causing such accidents. As such, 106 accident reports related to moving parts of machinery from the province of Quebec in Canada have been analyzed. The main causes are easy access to moving parts of machinery, lack of safeguarding, absence of lockout procedures, inexperience of workers, bypassing safeguards, lack of risk assessment, lack of supervision, poor machinery design, unsafe working methods, no clear instructions to workers on how to intervene safely on machinery as well as modifications to machinery and to control systems. Prevention strategies are also proposed based on the findings and on the literature.

1. Introduction

A machine is defined as an assembly fitted with or intended to be fitted with a drive system consisting of linked parts or components at least one of which moves, and which are joined together for a specific application (ISO 12100). Machines contain hazards of different nature and exposure to those hazards can result in injuries or deaths. Different types of machinery hazards are listed in (ISO 12100; CSA Z432; ANSI B11-TR3; Bluff, 2014). These are structural (e.g. sharp edges, projections), mechanical (e.g. entanglement crushing, cutting), physical (e.g. electricity, pressurized content, noise and vibration, hot or cold temperatures), ergonomic (awkward working positions, manual handling, repetitive movements), slip/trip/fall (e.g. poor walkways, railings), chemical (e.g. gases, fumes, liquids), end use conditions (e.g. location, impact on workplace layout) and biological (e.g. bacteria, mold) (Bluff, 2014). Since workers intervene on machinery in all the phases of its life cycle, i.e. installation, operation, maintenance, troubleshooting, repairs, adjustments, set up, handling production disturbances, cleaning and dismantling, they are exposed to hazards. Actually, numerous accidents are related to machinery.

1.1. Statistics of machinery related injuries and fatalities outside Canada

Machine related accidents in the US caused 8505 fatalities between 1980 and 1989 with an average annual fatality rate of 0.8 per 100 000 workers (Pratt et al., 1996). The highest industry-specific rate was noted in agriculture, forestry and fishing. Etherton et al. (2001), while citing US Bureau of Labor Statistics data, report that 464 occupational fatalities occurred in the US between 1966 and 1998 resulting from being caught in running machinery. The Bureau of Labor Statistics in the US (BLS, 2014) revealed that a total of 717 fatal work injuries occurred as a result of contact with objects and equipment in 2013. This number includes 503 workers who were fatally injured after being struck by objects or equipment. Out of the 503 workers, 245 workers were struck by falling objects and equipment other than powered vehicle and 29 workers were struck by discharged or flying object. 131 workers were caught in or compressed by equipment and objects, including 105 workers being caught in running equipment or machinery. 78 workers were struck, caught or crushed in collapsing structure, equipment or material. The HSE reports that 50% of accident related to moving parts of machines in UK occurred in printing presses and conveyors (HSE, 2006). Bulzacchelli et al. (2008) report that in 2005 just over 1000 (i.e. 18%) of workers

* Tel.: +1 514 3404711x2268.
E-mail address: yuvin.chinniah@polymtl.ca

http://dx.doi.org/10.1016/j.ssci.2015.02.004
0925-7535/

fatally injured in the US were by contact with objects and equipment. Bellamy et al. (2007) report that annually about 400 accidents, i.e. 21% of total accidents per year in the Netherlands, are caused by contact with moving parts of machinery. Gardner et al. (1999) report that in Australia, mechanical equipment injury accounts for 28% of all compensation injuries. Gerberich et al. (1998) report that agricultural machinery has been identified as a principle source of non-fatal injuries in the rural sector.

1.2. Machinery related injuries and fatalities in Canada

In Canada, there were approximately 3 occupational fatalities each day of the year in 2008 (Gilks and Logan, 2010). Also in 2008, approximately 1 worker out of every 13 805 workers covered by provincial or territorial compensation systems died from an occupational injury. On average, 1 out of every 46 Canadian worker covered by provincial or territorial compensation systems was injured severely enough to miss at least one day of work in 2008. The working compensation boards paid $7.67 billion in benefit payments or an average of approximately $22 845 per each new compensated time-loss injury or fatality. In addition, $2.03 billion in health care and vocational rehabilitation payments were made in 2008. Including these costs, the total direct annual costs of occupational injuries and fatalities to the Canadian economy were approximately $9.7 billion in 2008. If the indirect costs are included, the total costs of occupational injuries to the Canadian economy can be estimated to be more than $19 billion annually. In Canada on average 177 hospitalizations per 100 000 people are reported annually due to agricultural machinery injuries (Brison et al., 2003). A total of 159 machinery related injuries on 2390 farms in the province of Saskatchewan in Canada were reported in 2006 and these agricultural injuries were due to machinery such as tractors (23%), transportation equipment (16%), harvesting equipment (16%), augers (11%) and combines (11%) (Narasimhan et al., 2010). In Canada, national statistics on the number of machinery-related accidents, apart from agricultural machinery injuries, are not available.

In the province of Quebec in Canada, between 2000 and 2004, there were 770 agricultural machinery related injuries, which represented 12% of the 6604 occupational injuries in the agriculture sector (CSST, 2006). In Quebec, between 1989 and 2003, 12% of fatal injuries on farms were caused by moving parts of machinery. In 2005, the OHS regulator for Quebec, the CSST, revealed that around 13 500 machinery related accidents and 20 deaths occurred annually in the province (CSST, 2006). Moreover, the CSST has introduced in 2005 a safety of machinery action plan to educate machine suppliers, employers, workers and other associations about the risks associated with machinery. The action plan focused on access to moving parts of machinery. In 2010 the CSST revealed that 3552 workers were injured as a result of an accident linked to a machine. Between 2006 and 2010, on average 12 workers were killed each year as a result of work accidents related to machinery. Due to the action plan of the CSST which began in 2005, the number of annual machinery accidents has dropped significantly. In Quebec, section 21 of Occupational Health and Safety (OHS) regulation, the RSST, addresses safety of machinery (regulations 171–226). In essence, the RSST states that machines must be designed and built so as to make their hazardous zones inaccessible. Hazardous zones relate to any area in or around a machine that presents a risk to the health and safety of the worker. The law on OHS states that employers have legal responsibilities when purchasing machinery, installing machinery and supervising employees operating and intervening on machines. Employers need to identify and manage risks associated with machinery. Machine builders and suppliers need to ensure that their machines are safe. Workers using and maintaining machines need to abide to safety procedures and take all necessary measures to prevent injuries to themselves and others. In Quebec, if the health or the safety of an employee is directly and seriously compromised by the use of a hazardous machine, the employer may be liable to a fine ranging from 15 000 $ to 300 000 $ CAD. The employers can also face criminal charges for negligence.

The literature in the field of safety of machinery is rich and consists of machine safety standards, regulations, peer reviewed and non-peer-reviewed journal and conference papers, books, guides, leaflets and checklists. The CSST has compiled a list of 415 safety of machinery standards from ISO, IEC, CSA, ANSI and EN. Increased pressure to comply to existing regulatory framework, more frequent OHS inspections in companies by CSST inspectors, availability of information from the literature as well as training of engineers, CSST inspectors and OHS personnel in the field of safety of machinery combined with research on safety of machinery have all contributed to the reduction in machinery related injuries and fatalities in Quebec. It is important to understand the causes of accidents in order to identify potential solutions to further reduce the number of injuries and fatalities. The causes of machinery-related serious and fatal accidents in Quebec have not been studied.

1.3. Literature review on machinery related accident reports

Backstrom and Doos (2000) report problems related to safety devices from 76 accidents in automated production obtained from 21 work sites in Swedish manufacturing industry over a two year period (1988–1990). The study reveals that a production installation should not be regarded as safe simply because it possesses safeguards. The latter include barriers, interlocks, hold to run control, two hand controls and presence sensing device. The study identifies four levels of problems namely: (i) no or low level of safeguarding, (ii) non-use of safeguards (remove, circumvent, defeat, decouple), (iii) failure of safeguards to stop all machine movements in the danger zone (residual energy, inertia) and (iv) failure of safeguards to provide protection under all prevailing circumstances (e.g. work requiring machine to be energized). It is shown that all types of safeguards have their problems. Safeguards do not always function adequately in conjunction with the handling of production disturbances.

In another study, 592 lockout/tagout related incidents in the US resulting in a total of 624 fatalities were reviewed (Bulzacchelli et al., 2008). In the majority of cases (70%), lockout procedures were not attempted at all. There were very few incidents in which a lockout attempt was made and a fatality occurred due to human error (5.2%) or mechanical failure (1.2%). This small proportion suggests that lockout/tagout procedures, when properly used, do indeed prevent fatalities. Several strategies to increase the use of lockout/tagout are proposed. The author recommends further research on understanding barriers to following lockout/tagout procedures and finding ways to increase usage of these procedures.

Shaw (2010) reviewed 100 incident investigation reports in the UK spanning the period 2002–2007 and identified a number of contributory causes. The review revealed that inadequacies in design, failures to isolate (lockout), defeating protection system, inadequate fault reporting or maintenance were major contributors.

Blaise and Welitz (2010) retrieved from the French EPICEA database, 88 accidents between 1998 and 2007 involving machinery during non-production phases (i.e. maintenance). The study reports that operators also perform maintenance actions. The distribution of non-production phase machinery accident according to the risk factors were classified as: (i) organisational aspects (69%) corresponding mainly to compliance with procedures, in particular isolation/lockout, (ii) technical aspects (51%), i.e. maintainability, lack of protection or inadequate protection and (iii)