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Safety of industrial machinery in reduced risk conditions

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ABSTRACT

Industrial machines are known to possess many hazards. One machine safety design requirement found in the machinery directive in Europe, national or provincial legislation in North America, as well as national and international safety of machinery standards is the control mode for maintenance when guard or protective device has to be displaced or removed. One of the conditions is that the control mode permits operation of the hazardous elements only in reduced risk conditions. This condition presents some challenges to designers and users alike. What are considered reduced risk conditions is open to interpretation. The objectives of this study were to identify values for safe reduced speed, safe kinetic energy and safe contact pressure from the literature and from enterprises and to identify the factors influencing the choice of values. It was found that values for reduced speeds, force, energy, contact pressures varied widely. Industrial visits showed that enterprises use reduced speeds by switching to the reduced speed mode of operation without applying the other required conditions. Machines were modified to incorporate this mode of operation indicating some design problems. Some factors were identified which could guide the choice of values when the information is missing from standards or other documents. When a safety standard exists for a particular machine and that the values are specified in the standard, designers and users can use those values. However, if the machine has no safety standard, a risk assessment is needed before deciding which values to use.

1. Introduction

Industrial machines are known to possess a multitude of hazards. ISO 12100; CSA Z432; ANSI B11-TR3 standards describe different types of machinery hazards. Bluff (2014) lists the hazards found in machinery as 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). 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 and they are exposed to hazards.

1.1. Accident statistics

Machines cause several accidents in the workplace. For the years 2003 to 2010, 5579 occupational machine-related fatalities were caused by machinery in the Unites States (US) (Marsh and Fosbroke, 2015). Mobile machinery accounted for 4282 fatalities and stationary machinery for 1297 fatalities. The three industries with the most fatalities were agriculture and fisheries (37%), construction (22%) and manufacturing (14%). Tractors, forklifts, earthmoving machines and cranes were the most hazardous mobile machinery. The Bureau of Labor Statistics in the Unites States (US) (BLS, 2014) revealed that a total of 717 fatal work injuries occurred as a result of contact with objects and equipment in 2013. The Health and Safety Executive (HSE) reports that 50% of accident related to moving parts of machines in the United Kingdom (UK) occurred in printing presses and conveyors (HSE, 2006). Bulzacchelli et al. (2008) report that in 2005 just over 1000 (18%) of workers fatally injured in the US were by contact with objects and equipment. Bellamy et al. (2007) report that annually about 400 accidents, 21% of total accidents per year in the Netherlands, are caused by contact with moving parts of

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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. Chinniah (2015) analyzed 106 accident reports related to moving parts of machinery from the province of Quebec in Canada and found that many accidents occurred during maintenance and the handling of production disturbances, when the operator entered a hazardous zone of machinery. The mechanical hazard was already present (e.g. rotating shafts) or appeared suddenly (e.g. blade starts rotating suddenly). It was found that 12.3% of accidents were linked to the set up phase, 19.8% of accidents to production tasks, 34.9% of accidents to maintenance tasks and 31.1% to handling production disturbances. The main causes were 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. Other studies have reported similar findings (Backstrom and Doos, 2000; Blaise and Welitz, 2010; Bulzacchelli et al., 2008; Charpentier, 2005; Shaw, 2010). Accidents involving machinery occur in many countries with different legal requirements surrounding machinery and using different safety standards. The causes of serious and fatal accidents involving machinery are similar.

1.2. Design requirements

Machine designers are required to carry out risk assessments and implement protective measures for all phases of the machine life cycle. Accident reports show that workers are injured and killed by machinery during interventions other than production, such as setting, teaching, process changeover, fault-finding, cleaning or maintenance. One important design feature on machinery includes the control mode for those interventions. This design requirement is found in legislations such as the machinery directive in Europe (The European Parliament And The Council of The European Union, 2006), national or provincial legislation of some countries such as US, Canada, France, UK and so on but with slight variations (Code du travail, 2015, Publications du Québec, 2015). This requirement is also described in international and national safety of machinery standards such as ISO 12100 and CSA Z432, with some slight variations. For instance, CSA Z432 refers to enhanced safety conditions. ISO 12100 and the machinery directive mention that the safety of the operator is achieved using a specific control mode which simultaneously satisfies four conditions. The first condition is that the specific control mode disables all other control modes in the machinery to ensure that another worker does not restart the equipment. The second condition is that the specific control mode, permits operation of the hazardous elements only by continuous actuation of an enabling device, a two hand control device or a hold-to-run device. This ensures that the worker has full control of the hazard. The third condition is that the specific control mode permits operation of the hazardous elements only in reduced risk conditions (e.g. reduced speed, reduced power/force, step-by-step using a limited movement control device). The objective behind this condition is to limit the severity of harm, increase the possibility of avoidance of harm by anticipating it and having enough time to react accordingly. The fourth condition of the specific control mode is that it prevents any operation of hazardous functions by voluntary or involuntary action on the machine's sensors. Moreover, additional measures such as restriction of access to the danger zone as far as possible, emergency stop control within immediate reach of the operator and portable control unit (teach pendant) and/or local controls allowing sight of the controlled elements are needed. Accident reports show that workers are injured and killed during the interventions covered by the specific control mode (Létourneau and Potvin, 2014; EPICEA, 2015). Moreover, the use of two hands control, continuous actuation of an enabling device, hold-to-run control to achieve the specific control modes is generally understood and quite clear. The third condition which is the reduced risk condition presents some challenges to designers and users alike. OHS personnel, labor inspectors, safety engineers, machine designers, and machine users experience difficulties to identify those conditions. This paper aims at exploring this issue both theoretically through a literature review and practically by observing how workers intervene on machinery using the specific control mode.

2. Objective

The first objective of this study was to identify values for safe reduced speed, safe kinetic energy and safe contact pressure for five types of industrial machines known to use safe reduced speed and energy, namely robots, machine tools, printing presses, paper machines and textile machines. The second objective of the study was to understand how the reduced speed and energy operating mode used for maintenance and other interventions is actually implemented in Quebec when a guard has to be displaced or removed and/or a protective device has to be disabled. The third objective was to determine the factors influencing the choice of values of reduced speed and energy in Quebec and the reasons for the use of those values when the information is absent from machinery safety standards or guides.

3. Method

The methodology consisted of a literature review which focused on five types of industrial machines known to use safe reduced speed and energy, namely robots, machine tools, printing presses, paper machines and textile machines. The Compendex database was used and keywords in English and French included: reduced speed, safe speed, limited speed, reduced power, limited effort, reduced force, safe force, contact pressure machine reduced energy, maintenance and safety, robot safety, printing press, paper machine, textile machines, conventional lathe, CNC lathe, controlled sustained action, maintaining control mode, low speed cleaning, robot programming, robot learning mode. The search resulted in 78 being retained for analysis, namely 55 standards, 14 guides, 11 scientific papers and two research reports. The useful information in each document was copied and classified in an Excel spreadsheet. This allowed to extract the important concepts, analyze and categorize them (e.g. recommended value, type of hazard, other associated protective measures). One limitation is that the search methodology through Compendex database is not reproducible.

Once the recommended values from the literature were collected, the second part of the methodology was conducted in order to understand how reduced speed and energy were actually implemented. It consisted of carrying out industrial visits in enterprises in different types of sectors to (i) understand and characterize the context surrounding the interventions in reduced speed and energy mode, (ii) note and measure, if possible, the values of reduced speed used, (iii) understand the choices made and to identify the references used by enterprises and (iv) determine the factors influencing the choice of values and the reasons for the use of those values. The selected enterprises were using safe reduced speed and energy on industrial machinery. Data on safe operating