# State of the Art Review of Accidents Due to Moving Parts of the Machinery in Industries


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## 1 Introduction

Machines are hazardous in nature and exposure to the hazards may cause accident that could be fatal accident. Objective of this paper is to suggest techniques and technology in order to make machine activities safe and bringing the hazards to the acceptable level. Before suggesting any technique and technology to make machine activity safe, it is necessary to find out the causes of accident that are due to moving machine parts. Moving parts of the machinery can be operated anytime so the risks of accidents are likely to happen frequently (Chinniah 2015). Lots of accidents occur from moving parts of machinery. With the system as well as technology advancement, the frequency of the accident has increased. The reason behind it is unpredictable motion of the machine due to the command from its control system. There are standards and regulations on the machines control system. For the safe functioning of moving parts of machine, it is necessary to follow these standards. Before talking about the accident and the prevention of accident from moving machine parts, it is necessary to define what a machine is.

A machine is an apparatus that uses mechanical power and also have many components that have desired task to perform and components all together perform a particular job. There are various types of machine. A lot of hazards are associated with the moving parts of machinery which results into day by day increasing fatalities and deaths which includes injuries of entanglement from rotating shafts, cutting from sharp edges of machines, crushing of hand, arms and fingers from hard surfaces of machines which move together, puncturing, sudden impact, etc. (Dźwiarek and Latała 2016). Each accident has three phases: first phase is pre-accident, second phase is accident phase and the third phase is post-accident (Hoła and Szóstak 2017). When

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a person is working near moving machines without proper safeguards and safe work practices, they can be struck and seriously injured or it may lead to fatal accidents. Sometimes, due to not having control on machines as well as sudden start or stop with change in speed due to system failure also led to harm to the life of people. The conditions which pose a threat to such accidents are installation of machines and equipment, operating machines and equipment, maintenance or repair services and cleaning services. Crushed hands, arms, fingers and legs are the possible injuries caused by the moving machines. Sometimes, the parts of the machines can be so hot and cold that it leads to burns. A condition such as when the screws, nuts, bolts or other fixed guards used in the machines loose and comes out during work performance; it is also responsible for injury or accidents to occur. Before talking about prevention of the accident, it is important to go to the depth of any accident and to reach out to its root cause. These causes can be from manufacturer end or the user end. Manufacturer causes of the accident are incorrect definition of safety functions, incorrect formulation of safety requirement, manufacturing fault in the machine, incorrect power and phase rating as well as user manual error. User causes of the accident are poor training/untrained worker, poor maintenance and not following the safe work practices. There are various sectors of organization in which large amount of fatality occur every year due to moving machinery. Majorly, construction sector, agriculture sector, wood industry, metal manufacturing industry and industry using robots are the major sectors where most of the accidents occur due moving parts of machine.

To prevent the accidents from moving machine parts, it is necessary to identify the root cause of accident. Elimination of root cause of accident prevents it in occurring in future. To prevent the accident and to find out the root cause, there are various techniques that have been adopted till now. Some of the effective techniques reviewed are safety climate and communication, sensor-based technology, injury survey, accident investigation method, safety assessment system, HAZOP-UML method, fault diagnosis method, logic analysis data, simulation model technique, failure mode and effect analysis (FMEA) and fault tree analysis (FTA). Now to prevent the increasing fatal accidents and injuries from the machinery, it is necessary to adopt safe working practices, devices and safeguards. Some of the safe working practices include training plan outlines, process of ensuring compliance, orientation of new and returning worker, following up the standard operating procedures, use of personal protective equipment, reduce workplace stress, report unsafe conditions to the supervisor, keep emergency exits accessible, take regular breaks and be aware of your surroundings. Some of the safety devices includes safety light curtains, safety controller, two-hand control device, indicator lights, safety scanner, safety interlock switches and enabling devices, tower light and emergency stop and stop control. Some of the safeguards include fixed guard, distance guard, adjustable guard, tunnel guard, fixed enclosing guard, interlocking guard, automatic guard, trip devices, two-hand control guard and reaching over guard.

Currently, sensor-based technology, machine guarding, training and use of PPE are the most effective measures taken by most of the industry to prevent accidents from moving parts of machine. Still the accidents from moving machine part are

at high rate. So, in this paper, various new technologies and methods are available or they are in research phase to reduce the accident rate. Behaviour and attitude towards the safety, i.e. safety culture also plays a vital role in accident prevention in any organization. 88% of accidents occur due to the unsafe act. So the method of job rotation has been adopted by many organizations to prevent accident from unsafe act. It is challenging to control or modify the behaviour of any person towards safety and that is one of the major reasons of the accident.

## 2 Various Sectors Involving Machinery Accidents

### *2.1 Construction Sector*

Backström and Döös (2000) analysed that there were accidents despite the use of machine safeguards. According to them after using the machine safeguards, accidents were not prevented as according to them safeguards cannot stop all the machine movements. They concluded that safeguards do not function adequately because every safeguard cannot be considered as safe for same type of machines every time and different installations have different safeguards which work or perform up to a set range.

McCann (2006) identified that the contact with the heavy machines and the equipment with the workers at the construction area was considered as the most dangerous event which caused nearly 253 deaths in work industries because of backhoes and rollovers. Heavy loaded equipment caused the sudden jerk to the workers. Even some of the workers were barefoot and without proper personal protective equipment. As a result, LOTO procedures were used. Restriction to the specific zones was made where heavy equipment was installed. Setting of spotters at nearby places where such kind of activities was carried out.

Baksteen et al. (2012) found that lots of risks are associated to the workers working in the close proximity of the moving machines. A risk assessment was done to determine the risk. Identification of the reasons of the accidents led by these moving parts was conducted to determine the possibility of accident. They concluded that the accidents have categorized according to the different working conditions with the machines. For example, it could be anything related to cleaning, operating and maintaining machines. Measures were taken to decrease the fatality and permanent as well as temporary injury risk.

Choe and Leite (2013) found that sensor-based proximity warning technology in equipment helped in preventing back-over accidents in construction zones. This includes the selection of generic sensor system and performance is tested. This is implemented in work zones which can prevent injuries and fatalities. Back-over accidents are due to the limitations in the visibility. Technologies which have been added to remove this causality are video cameras, micro-cameras, tag-based cameras, radar and ultrasonic which gives the clear view and prevents the accidents.

Poisson and Chinniah (2016) observed that there is risk related to machinery in sawmills. So they worked on eight sawmills containing machines such as hydraulic equipment, vertical and circular saws and chain conveyors. Workers could be crushed easily. Even there are chances of entanglement of body parts as well as cutting of body parts during cleaning, dismantling, repair, adjustment, set up, production disruption, installation, maintenance, unjamming, sharpening of blades, etc. Seven lockout programs were followed. Basically, this paper tells us how the logout procedure is implemented in proper way. Fifty-seven lockout procedures were also observed with the energies that are hazardous and controlled by circuit breakers usually (isolating), switch gears, pneumatic and hydraulic valves. Use of padlock was also implemented. Chemical and radiation energies were also used.

## *2.2 Agriculture Sector*

Kumar et al. (2008) analysed and found agriculture sector is one of the most illiterate and unorganized sector. The sharp turn taken by the operator, uneven land conditions, sudden applying of brakes while moving in high speed, poor functioning of brakes, accelerators and handle, and excessive load carried by the tractor are some of the causes of the accidents. But still the majority of the accidents happen because after suggesting techniques, still there is no effectiveness. Accidents are not recorded and there is no recorded data for the past accidents. In agriculture sector, maintenance and repair job are done by untrained person with time constraints and this is not done periodically. So, this result into a large number of injuries.

Narasimhan et al. (2011) evaluated that the machinery entanglement is one of the injury for the Canadian farmers during adjustments of machines parts, handling of products, clothes stuck with the sharp pointed parts of the machine or their attachments, during handling harvesting equipment for grains as well as seeds. The reasons were that the machinery was not operating properly, there was no proper guarding, there was no repair and maintenance, there was no safety sign, working hours were more than 20 and farmers were under time pressure. So this could be prevented by the safety attitudes, proper knowledge, changing perception towards safety, following the safety standards, farming procedures as well as maintenance.

Pawlak and Nowakowicz-Dębek (2015) observed that the most of the accidents occurred due to being struck by the heavy machines, misuse of the machines, such as automatic in row weeder, olive harvester, carrot harvester and separator, tractors, baler, cotton picker, loader and threshing machine, in agricultural holdings. As a result, farmers should know about the importance of learning safety instructions and safety regulations and even to get the vocational training.

Poisson and Chinniah (2016) discussed the smart machines which use sensor technology as well as robotic technologies in agriculture field for activities like seeding, harvesting, spraying, etc. Modern technology can prevent injuries by implementing advances in sensing hardware, software algorithms, data structures, smart systems and smart equipment. This is done for diagnosing the fault in the system of machines,

monitoring the work progress and safety of workers from the fatalities and injuries through safety driven-based old technique machines. It improves the efficiency of workers working with the new advanced machines with their high tech boosting system with the help of hybrid engineering and integrated systems applied to them. This reduces the worker's risk of entanglement and serious injuries.

## *2.3 Wood Industry*

Pavlovic and Fragassa (2016) observed that the relation between the workers and machines is uneasy and quite risky during woodworking where the machine can do cutting, shearing as well as drilling. Technology makes the machine safe. Manual machines may harm operator by its moving parts. Manual, automatic and computerized numerical control (CNC) machines are dangerous in their aspect. Accidents related to machines mostly comprises of removing swarf, taking measurement, unloading and loading components. In this, machines have sensing devices which creates an invisible layer of sensing field around the machine and it prevents the body parts of worker from getting caught in the moving machine. As soon as the machine detects the presence of human, machine stops immediately.

Osakwe et al. (2017) discussed the processing activities at wood workshop which comprises of lifting, cutting and stacking. Out of these, the major accident occurs due to revolving and reciprocating cutting tool used for wood processing activities. It may cause injury or death. Here, to prevent accidents, a new technology has been created. They have used human shields as a barrier for face, internal and external organs, skin as well as bones for protection against moving parts of the machine, coming into contact with the rollers, slip and trip. Fault tree analysis and Lagrange's multiplier were used to determine the fault in wood workshop which causes fatalities.

## *2.4 Robot Related Workplace Accidents*

Jiang (1987) analysed 32 accidents from the robots and studied the type of injuries, degree of injury and categorized it into design of robot, design of workplace, error of human and he came into the finding that the line workers were in more risk as compared to maintenance workers and programmers. Accidents from robots occurred due to poor workplace design and human error. 56% accidents occur due to pinch point and 44% are impact accident.

Vasic and Billard (2013) discussed that the robots apart from being the best technology to help the human can also harm the humans. There are two possibilities of accidents from the robots: due to robot-robot collision or robot-human collision. Robot-robot collision occurs when two robots operating in the small area collides. Robot-human collision occurs when operator comes in close proximity or on the path of movement of robot's arms. The three major causes of the accident through robots

are engineering fault, human error and working condition. Robots are programmed with software for safe working, but still accidents occur because the robots are not tested at lower speed at different working conditions before using it practically.

## 2.5 Accidents Investigation on Ships

Schröder-Hinrichs et al. (2011) carried out the accident investigation on ships using Classifying the system and human factor analysis for the causalities as well as incidents from the machines which leads to fire and explosion due to poor machine designs, poor techniques, failing of engines, wrong decision taken during the operation, faulty equipment, poor machine layout and improper space given to machines for their working. This also includes lack of organizational factors, lack of resource management, environmental factors, unsafe supervision, etc.

## 2.6 Various Accidents Due to Model and Technology

Bellamy et al. (2007) a research project was taken to build a casual model named as "story builder" for the scenarios which are mostly occurring and which has caused injuries to the workers. The tool classifies the data from accident reports. It also tells us the details of the failure of barrier to prevent accidents. A number of task groups have been allotted to identify and analyse the actual reason of the accidents apart from the other pathways. The result was that there should be selection of effective strategies to reduce the risk which takes into account the costs of accidents and proper measures should be taken. A proper ladder to analyse the accidents should be used which includes how the accidents occurred and at what time, failure of the accidents, number of risks involved during the work and type of work conducted during the accidents.

Backström and Döös (2007) found the data that comes from two engineering plants. They analysed the severity of the injury and the body part injured between advanced manufacturing accidents (AMT). Automated machines improve the production efficiency and also it makes working environment better. With the help of technology development, conventional reasons of the accidents are eliminated but new kind of accident arises. They concluded that AMT accidents are more harmful as compared to the other accidents because of the day by day growing technology, and these accidents were considered to be the most serious ones.

Caputo et al. (2013) observed that safe machines contribute to safety in workplaces. Safety of machines is in the hands of safety devices. In this conclusion, there is reduction of mechanical hazards of the machines used in the industries. Proper safety devices are used for different machines because every machine has different safety devices which resulted in decline of accidents. Devices were checked by the decision makers based on expert opinion and keeping safety factors in mind.

## 2.7 Accidents Due to Machine Design

Driscoll et al. (2008) aimed to give a statistics of the contribution of fatal work-related injuries. The results were that the 37% of fatalities at workplace had machinery design-related issues like improper guarding; improper protection from the fall heights, improper seat belts and failure of lifting. Design plays a vital role in the accident prevention that is related to moving parts of machine. Lack of incident data from accidents is one of the limitations of this study. Apart from this, even the design of machinery and leads to serious accidents in an increasing number. Proper safety should be considered while designing any machines, plant layout as well as equipment.

Dźwiarek and Latała (2016) analysed 1035 serious accidents out of which 341 were minor injuries. Moving machinery can be made safer by the manufacturer by using protective devices, safe design and safeguarding. On the other hand, machine can be safe by the user end, if the operator follows standard operating procedure (SOP), i.e. written and verified procedure to use the machinery safely. SOP plays the vital role in every industry having moving machineries in minimizing accidents due to wrong or unsafe work practices. Here, nine types of machine operations were used for different tasks with the help of rotating working elements of the machine and moving transmission parts in manufacturing sector.

## 2.8 Techniques Adopted to Prevent the Accidents from the Moving Parts of Machinery

The major objective of this review paper is to find out the main causes which lead to accident and injuries and also to suggest what other preventive measures can be taken by adopting effective and suitable methods. The studies have been made by adopting certain methodology to improve the statistics of increasing number of accidents which occurs during dismantle of the machinery and equipment, operating machine and equipment, providing maintenance or repair services, cleaning services, production from the different industries, etc. Accident investigation finds out the root cause of the accidents. There could be occupational factor (culture, environment, equipment, workload, working hours), human factor (motivation, training, physical and mental capability, medical conditions, alcohol and drugs) and technical factor (poor functioning of machines, no guarding, no warning signs, no warning devices, no warning signals, no complementary protective devices, etc.). Now there are certain areas where different methodologies have been used to prevent accidents.

### *2.9 Safety Climate and Communication*

Hofmann and Stetzer (1998) observed that the underlying cause of any machine accident is necessary to be identified correctly in order to prevent the accidents occurring in future. In this adopted methodology, two types of surveys for the interpretation of accident such as safety climate and communication were carried out. Safety climate measures the importance of safety to the management, priority of the safety to their supervisor, availability of the safety equipment, strength of the safety policies and awards for achieving the safety standards. Safety Communication measures the extent to which workers are comfortable talking about safety with their supervisors.

### *2.10 Sensor-Based Technology*

Roca (2006) suggested the machine protection system and method for rotating equipment which tells about the new alarming features and use of sensors to get the information such as thermal information, chemical, motion and force. Here, the amplitude vibrations are sensed and phase data is stored on a minute basis and hour basis for short term and long term by calculating the average of vibration amplitude baseline. If the alarm gets triggered on exceeding the sensed vibration amplitude from baseline vibration amplitude or through current deviation, the rotating machine will stop or shut down immediately.

Zhang et al. (2017) investigated and provided a review on the technology which was sensor based on advanced construction of safety management for accidents. There are few technologies which are used nowadays such as vision-based sensing technology, sensor-based technology, location sensor-based technology, wireless sensor-based technology, etc. In this paper, the use of different types of sensor-based technology has been identified and reviewed. Identification of radio frequency, network based on wireless sensor, system that provides pre-warning, and Zigbee was used to prevent accident.

## 3 Injury Survey

Robert et al. (2008) analysed and suggested a methodology to prevent the accidents from machinery. It is necessary to do the injury survey. To conduct this, questionnaires were made that are specific to machines and 201 injured persons were interviewed on the basis of categories of machine and the circumstances at the time of accident. This method helps in finding out the shortcomings that may be machine related or machine part related or safety measures related to machine.

## 4 Accident Investigation Method

Katsakiori et al. (2009) evaluated that the accidents from the machines were investigated but it is necessary to evaluate the effectiveness of the current investigation method. Investigation method is considered to be effective if it clearly specifies immediate and underlying cause. Evaluation of current accident investigation is one of the methodologies to prevent machine-related accident in future. Evaluation of the current accident investigation is based on the accident model, safety improvement recommendations, detailing of the machine accidents, validation of the accident investigation method, training and education required in order to conduct the investigation.

## 5 Safety Assessment System

Kim et al. (2016) observed that despite the safety guidelines, workers do not follow safety rules every time. So through this paper, an onsite safety assessment system was adopted based on computer vision and fuzzy interference for the accidents which occurred due to strucking from moving objects. Safety level will be shown as numerical value. Through this, current working condition of the workers can be improved.

### *5.1 HAZOP-UML Method*

Guiochet (2016) identified a new method HAZOP-UML. HAZOP method was combined with the system modelling language, i.e. (UML—unified modelling language). A prototype was originated to provide the better ease to HAZOP table and UML models. HAZOP-UML table consists of guide word line number, attribution, deviation, real-world effect, use case effect, every possible causes, severity, remarks, safety recommendation and hazard number. But there was a drawback related to this method that it is difficult to determine hazard as three columns represent the hazard such as deviation, use case effect and real-world effect. Apart from this, there is no method available to determine the actual environment conditions of the execution.

### *5.2 Fault Diagnosis Method*

Shao et al. (2017) developed a method for detecting the rotating machinery fault. This method is applied to rotating as well as bearing applications. It is a method in which raw vibration data is taken and after that we can detect the fault diagnosis

result. We do not have to be dependent on signal processing techniques and to extract manual features.

### 5.3 Logic Analysis Data

Jocelyn et al. (2017) found that logical analysis of data (LAD) was a great idea to prevent the accident that is related to moving parts of machine, when the belt conveyors were used. LAD is a computational technology. With the help of LAD, accidents of different natures were categorized with an accuracy of 72–74%. LAD provided the different patterns generated in a logical way by using this as algorithm to prioritize the risk factors and this thing helped the operators as well as practitioners to make decisions regarding safety.

### 5.4 Simulation Model Technique

Hoła and Szóstak (2017) analysed that the construction site was prone to the accidents that cause injury or death. There are various causes of accident at construction site out of which one of the reasons was the accidents from moving parts of the machine during operating, transporting, servicing, etc. The proposed methodology had majorly five steps: collecting the data sources, acquiring the protocols of accident investigation, creating a database, constructing a stimulating model and testing of the models. The overall objective is to develop a model for stimulation of the accident and test the derived model.

### 5.5 Failure Mode and Effect Analysis (FMEA) and Fault Tree Analysis (FTA)

Kan et al. (2018) evaluated that large no. of accidents and injuries occur from cranes that are used at construction. Most of the accidents are related to the bolts, pin, safety device, hook, twisting part of the machine such as coiling, hoist and load indicator. Now there are two types of methods used to prevent accidents and to know the reason of crane failure, i.e. fault tree analysis (FTA) and failure mode and effect analysis (FMEA). FMEA tells about the failures which are related to the machine failure but FTA tells about the failures which are related to the machine, human errors, environmental factors as well as factors related to the reliability. FMEA takes the help of data and humans that are expertise and thus they prevent the crane failure but FTA concentrates more on the results that occur in the end and at the last finds out the causes which lead to the accident.

## 6 Result and Discussion

Machine design-related issue causes 37% of the fatal accidents. The effective strategies can reduce the risk and in turn will reduce the cost of accidents and injuries. At construction site, workers getting in contact with moving machines cause most accident. Proximity sensors play vital role in backover accident prevention at the construction sites. Sawmill is one of the dangerous industry. People may suffer from cut, crush from machines of sawmills. Different types of safeguarding should be done for the different types of machine for getting the effective isolation from the moving machines. The technology such as sensing, hardwares, software algorithms, data structures, smart systems and smart equipment are modern techniques for the accident prevention and fault diagnosis. Wrong and unsafe practices can be prevented by standard operating procedures while working with moving machineries. Robots fall under the category of moving machines and most of the accidents from robot occur because of the poor workplace design and human error. Safety devices installed in the machines prevent many accident from moving machines. Other measures to reduce accidents from moving machines are less working hours, machine maintenance, adequate training, changing the perception towards safety and following the safety standards.

If the hazard cannot be controlled at the source, personal protective equipment work as a barrier between the worker and the hazard. In the case of machines, coming in contact with the moving machine parts is the hazard which may lead to injury or fatality. There should be 2D barcode on the every personal protective equipment and workers should get scan all the personal protective equipment in the barcode scanner machine where barcode needs to get access and then only the machine will get start. It should be software-based automatic system. Machine should get on only once the mandatory personal protective equipment barcode is being scanned.

## 7 Conclusion

Although most of the industrial sectors that comprise machinery with moving parts form a major source of productivity, agriculture and construction sector are the most prone to accident from moving machineries. After reviewing the papers, certain measures can be concluded that human error is one of the major causes of accidents from moving parts of machine. Effects can be from minor injuries to fatal accident. Other reasons that resulted in accidents are machine fault, design fault and poor safety culture. The hierarchy of control is applicable to any found hazard in the workplace and the relevant control strategy can be implemented depending on the type of hazard and the work floor environment. Most of the machines the elimination and substitution of the hazard are not possible as it is a part of the inherent design so engineering control, administrative control and personal protective equipment plays a major role. These accidents from moving parts of machine can be prevented by

technology like guarding and guarding devices, implementing standard operating procedure (SOP) or by behaviour change towards safety and also correct mode of accident investigation prevents accident from reoccurring.

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