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THE MACHINE OPERATOR'S JAMMED-FEEDSTOCK-CLEARING TASK: A SAFETY DESIGN CHALLENGE

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ABSTRACT

Workers are often exposed to injury risk from sudden and unexpected machine movement when clearing jammed material from process machinery. An engineered safety response can effectively intervene to control or eliminate this risk. Backstrom and Doos (1998) found that about 25% of injuries involving automated machinery were preceded by a disturbance in process material flow such as a piece of material becoming stuck, crooked or getting in an otherwise faulty position. In the US, lockout is required when an employee is required to place any part of his or her body into an area on a machine or piece of equipment where work is actually performed upon the material being processed (point of operation) or where an associated danger zone exists during a machine operating cycle. Minor tool changes and adjustments, and other minor servicing activities, which take place during normal production operations, are not covered by the OSHA lockout standard if they are routine, repetitive, and integral to the use of the equipment for production, *provided that the work is performed using alternative measures which provide effective protection* [emphasis added] (OSHA,1989). Machine control systems that can automatically detect and respond to hazardous operating conditions could be a way to reduce machine-related injury and fatality rates. Accurate laboratory testing criteria, based on key patterns manifested by the machine during hazardous events are vital to developing such new safety technology. This paper discusses safety design challenges in designing reliable safeguarding associated with machinery.

INTRODUCTION

Too many workers are killed on the job every year when their tasks bring them dangerously close to the hazards of running machinery (Pratt et al., 1996). Between 1992 and 1998, fatalities resulting from workers being caught in all types of machinery averaged 150 per year, with 189 fatalities in 1997 (Bureau of Labor Statistics (BLS), Census of Fatal Occupational Injuries (CFOI), 1992-1998). Also, between 1992-1996, serious nonfatal injuries resulting from workers being caught in machinery totaled 34,000 and were the leading cause of amputations among private industry wage and salary workers.

Human intervention into machinery systems often happens when material jams while it is being fed into the machine. Fully 10% of BLS CFOI narratives clearly specified that jammed machinery was involved and could easily have been a factor for other cases that did not have complete narratives. Although much is automated on modern machinery, most machines cannot unjam themselves. Workers must do it. Workers in the agriculture, manufacturing, and recycling industries (Table 1) are especially vulnerable (Windau, 1998).

Table 1 Fatalities in Some Machines Where Feedstock Often Jams (BLS, CFOI, 1992-1998)

Industry	Machine type that often jams	Total Fatalities
Recycling	Balers	31
Agriculture	Harvesting machinery	201
Manufacturing	Presses (injection molding, etc.)	49

A review of NIOSH's National Traumatic Occupational Fatality (NTOF) database (1980-1992) identified 27 fatalities involving stationary compactors and balers. Failure to lock out energy sources before clearing jams appear to be a factor in many of these incidents (NIOSH, 1999). NIOSH Fatality Assessment and Control Evaluation (FACE) investigations of more recent fatalities revealed two specific incidents in which personnel were inside the equipment and not following lockout procedures (NIOSH, FACE URL reference).

A machine is not necessarily safe when it is stopped (motionless). From a *machine operator's perspective*, a machine "stop" exists when a jam interrupts production flow. Too often, the focus of attention is solely on getting the system back into production, resulting in a restart of dangerous motion the instant the jam is cleared. From a *safety control system perspective*, a machine "stop" is achieved through the states of logic devices in the control system. Restart of a well-designed safety control can only happen when the logic devices return to the safe-operation state. A safety instrumented system (SIS) will read sensors, do calculations, and perform the logic required to identify potentially dangerous conditions, and generate outputs to actuators designed to mitigate the dangerous situation (Goble, 1998). Unfortunately, not all control system logic accounts for the undesired presence of a worker in the point of operation. Finally, from a *hazardous energy perspective*, "stop" includes locking out and relieving primary energy sources. Thereby, no energy is present and no injury is possible.

Descriptions of jams in balers

On large-scale recycling balers, several types of jams can stop production. An operator is expected to respond to these and return the baler to production.

Over-size bale: Too much material in the baling chamber. On hand-tied bales, when too much material wedges into the baling chamber, wire cannot be wrapped around the bale. Someone must access the loading chamber to remove material so that a properly sized bale can be wrapped.

Over-size material loaded: Too much heavy material at the shear zone. At the shear zone in a baler, the ram meets the open corner of the baling chamber. If there is too much material in this shear zone, the ram cannot shear through it as it

advances. Hydraulic system over-pressure relief causes the ram to reverse. Someone must access the loading chamber to remove this material by hand. Loading smaller amounts can avoid this.

Material bridges the feed chute. A person may try to jump on this bridged material from above to force it into the loading chamber. Ram motion can start automatically when sufficient material is in the loading chamber to block the light path of the photo-electric sensor. A person falling from above can interrupt the light path and start a cycle.

Potential causes of machine motion

While a person is clearing a jam, machine motion can occur for several reasons if power has not been adequately removed. Two types of energy need to be removed; electrical energy to pumps and directional control valves; and hydraulic energy stored in accumulators. Degraded operation of the following three components of a hydraulic circuit can have direct influence on the safety of personnel entering the point of operation (Foszcz, 1997).

1) Cylinder seal problems Hazardous motion can result should the cylinder ram drift (not hold in the position where it was initially stopped). Possible causes for this include: the directional control valve spool does not center; the valve spool does not shift completely; the valve spool or body are worn; the valve seats leak; or the piston seals leak. A cylinder may also drop a load being lifted even though the valve spool remains centered. This condition can result from: loose lines between the cylinder and valve; leaking or damage to the lockout or holding valve; broken springs on the lockout or holding valve; or leaking at the relief valve. Locking cylinders are a design option to consider.

2) Hydraulic direction-control valve problems Directional control valves direct or prevent flow through selected passages. Solenoids, hydraulic pilots, or mechanical linkages are used to shift the valve spool, which changes flow direction. Hazardous conditions arise when faulty or incomplete shifting occurs. Possible causes include: worn or binding control linkage; insufficient pilot pressure; burned out or faulty solenoid; defective centering spring; and improper valve spool adjustment.

3) Failure to discharge accumulator pressure Accumulators are pressure vessels in which hydraulic energy is stored and then released to even out the demand on the pump in circuits with uneven loading. The potential energy in an accumulator, when released into the system, can cause dangerous machine motion. In any accumulator circuit, a means should be available to automatically unload the accumulator when the machine is shut down. One way of accomplishing this is with a solenoid-operated 2-way valve that releases accumulator pressure to the reservoir when power is removed from the electrical control circuit. The solenoid must be energized to keep the valve closed.

RISK REDUCTION STRATEGIES

Given that the jam clearing task is high risk, highly reliable protective measures are appropriate. The risk control hierarchy is to 1) eliminate the hazardous task; i.e., no jams or fewer jams; 2) provide a well-engineered safeguard; i.e., not easily bypassed; and 3) provide worker training. While well-trained and supervised personnel can be a solution, worker protection should

not rely on training alone as the primary injury prevention method.

The current solution to dangerous restart of machinery is lockout/tagout training and implementation (Grund, 1995). Lockout/tagout required by OSHA (Standard 29 CFR 1910.147), is the protective procedure workers must perform to remove hazardous energy from machinery prior to performing maintenance and servicing tasks. All energy sources for equipment must be turned off or disconnected and the disconnecting device, switch, or valve locked and labeled with a tag warning not to energize the machinery. However, in 1998, lockout/tagout violations ranked fourth on OSHA's top 10 list of most frequently cited standards (3,532 violations) and fourth on the top 10 list of serious violations (2,537 serious violations). Also, minor tool changes and adjustments, and other minor servicing activities, which take place during normal production operations, are not covered by the OSHA lockout standard if they are routine, repetitive, and integral to the use of the equipment for production, *provided that the work is performed using alternative measures which provide effective protection* [emphasis added].

Because of these shortcomings with the training solution, the two strategies that are higher on the risk control hierarchy warrant further consideration. NIOSH and industry partners, within the framework of the National Occupational Research Agenda (NORA), have developed priorities for finding such alternative measures (NIOSH, 1998). The NORA Traumatic Injury research agenda calls for:

> 1) designing workplaces, machines, and equipment to remove the possibility of making unsafe choices or actions (engineer-out hazards); and
>
> 2) in designing and modifying workplaces to improve safety, "passive controls," those which do not require choices or actions by workers in order to be protective, should take priority over "active controls," which require workers to take action or change behavior.

ELIMINATING DANGEROUS PRODUCTION DISTURBANCES

Making machines less dangerous often is viewed as a function of new machinery design. But the metalforming industry, as an example, is adding new monitoring capabilities to existing presses to eliminate disturbances due to part feeding problems. Press load monitors have been used for more than 30 years to protect stamping presses and dies from damage due to overloads (Kuvin, 2001). These devices can also effectively reduce operator exposure to jam-clearing hazards. A normal load signature is established by the press manufacturer. During operation, the device compares the normal load signature with the actual force at that point in the stroke. Should the force exceed the normal value anywhere in the stroke, instantaneous machine shutdown is initiated to stop the press before the machine is damaged or a dangerous condition occurs. A great deal of benchtesting is needed to establish a safe-signature threshold and appropriate monitor locations. At its most sophisticated level, data can be fed back to the process controller to make automatic adjustments to compensate for the out-of-tolerance conditions.

In agriculture, jams form in somewhat different ways, but present similar hazards during jam-clearing. The buildup of jams in the feed rolls of harvesting

machinery such as hay balers, combines, and corn pickers depends on the forward speed at which the implement is gathering in crop stalks and the intake of extraneous weeds. Reversers on feed mechanisms on combines provide workers with a means to clear jams from the safety of the operator's control station. Interlocks are also required, where feasible.

FUTURE DIRECTIONS

Two directions in design improvement to mitigate the hazards of the jam-clearing task are indicated: 1) continue to install safeguarding that is not prone to human error/ misuse; and 2) develop better process monitors and controls that design out, or greatly reduce, the hazardous task exposure. Injury prevention efforts should be directed toward putting countermeasures in these categories into regular practice.

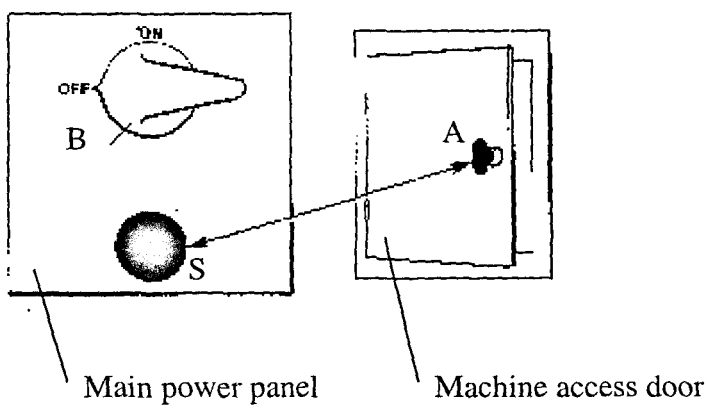

Figure 1 Key A is trapped in the door and can only be turned and removed when the door is closed, thus locking the door. Switch B cannot be turned to the ON position until key A has been inserted, turned, and trapped in lock S. Key A can only be removed from S when B is in the OFF position.

Safeguarding that removes the possibility of making unsafe choices

The trapped key method (Figure 1) is designed to combine the safety control stop with lockout in a manner that avoids human error. In a trapped key control system, power must be shut off before access can be gained through an interlocked door. Both the door and the power switch incorporate a lock. A removable key is trapped in either the door lock or the switch lock. The lock on the door is arranged so that the key can only be released when the door has been closed and locked. This allows transfer of the key from the door to the switch lock. Closing the switch traps the key, so that it cannot be removed while the switch is in the on position. A key exchange box is used if several sources of power are involved. However, to be most effective, duplicate keys should not be permitted.

Hazard elimination or reduction

Designing machine operation monitors that stop material processing and in-feed before a jam can form are the highest-level safety solution. An easier-to-

clear condition that can be accomplished from outside the danger zone eliminates the high-level hazard and replaces it with a much reduced one. Importantly, exposure time is reduced, or even eliminated. If some exposure, for a shorter period of time is necessary, then the monitor may be designed to automatically initiate the lockout process via the emergency-stop circuit of the machine.

Two design directions for making the jam-clearing task safer have been advanced in the foregoing discussion. The degree to which these design challenges are met, and design interventions put into practice, will have a direct bearing on the avoidance of future machine-related injuries and fatalities in the recycling, manufacturing, and agriculture industries. For its part, NIOSH will continue to follow the NORA research priorities that require laboratory testing and evaluation of new safety devices intended to protect against typical normal operation, caught-in-machinery hazards.

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