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PREVENTION OF INJURY ASSOCIATED WITH ROTATING ACTION MACHINES

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BACKGROUND

Repeated analyses of the Swedish national workers' compensation claims data material in the Occupational No-Fault Liability Insurance Scheme have pointed to the high incidence of severe hand injury associated with getting caught in rotating (drilling, milling, boring, turning, grinding) machines in the metal manufacturing and engineering industry (Jedeskog & Larsson, 1988; Larsson, 1990; Persson, 1992).

In an analysis of all permanently disabling injuries sustained in the Swedish engineering industry during 1986, six out of ten injuries associated with machines for drilling, boring and threading were caused by the operator getting caught in the rotating tool or work-piece with his/her glove or other garment (Larsson, 1990).

In a repeated analysis of the national claims data material from the Swedish engineering industry for the years 1987, 1988 and 1989, half of all injuries sustained at the same types of rotating machines were due to glove getting caught in the rotating action (Persson, 1992).

A development project aimed at reducing the risk of traumatic hand injury associated with rotating action machines was initiated in 1994 by the Institute for Human Safety and Accident Research (IPSO), in co-operation with the Swedish Institute of Production Engineering Research. The main focus of the work has been to develop an improved solution to emergency braking and to drastically reduce inertia rotation in the relevant machine types.

THE MACHINES

Pedestal Drilling Machine, Drill Press

The pedestal drilling machine is used for making single pieces or short series. The machine is usually applied for service when drilling, reaming, countersinking and threading may be carried out on small to middle-sized work-pieces. Typically the operators have their main task by some other machine with the pedestal drilling machine/drill press as a supplementary asset. There are several varieties of pedestal drilling machines/drill presses, eg. single and multi-spindle machines, bench and universal drilling machines. However, large series are usually tooled in NC machines.

Most pedestal drilling machines have a simple construction and do not seem to be complicated or dangerous, which might lead operators to underestimate its actual propensity to inflict severe injury. The injury information with the Swedish national workers' compensation scheme indicates that this machine type is associated with high proportions of permanently impairing hand injuries every year. Accident causes are often reported as human errors; the spindle has not been stopped after tooling while other operations are carried out; multi-spindle machines may have all spindles working simultaneously which increases the risk of getting too close and get caught by the sleeve, with some trinket or your hair. There is often very little space between several simultaneously operating machines. Cut wounds from drillings or small drillings or chips in eyes are also commonly reported events.

Radial Arm Drilling Machine

The radial arm drilling machines are used both for making single work-pieces and in series production. The size of the work-pieces may vary, but some of them are very big, heavy and difficult to handle. The spindle is radially moved and fixed to an arm which is moved in a circle. The radial arm drills are constructed to allow the operator to change tools while the spindle is still moving. As the time for braking the spindle is rather long, it is very common to continue with other sub-tasks while the spindle is running.

A considerable number of risks emanates from the pressure to continue with other working operations while the spindle is braking. As the setting of wages is changed from a piece-rate system to a fixed hourly wage, this cause of stress is reduced, but perceived time-pressure is still a major risk factor.

There is often no emergency brake and the only way to stop the tool is by setting the spindle start lever in its middle position. In an emergency situation there is a risk that the lever is pushed into its other extreme position, whereby the rotation direction is reversed and the injury is aggravated. Work-pieces may be badly fixed and fall from the bench with considerable force. The movable arm is heavy to maneuver and there is a risk that you slip when you put force to it, whereby you may get too close to the rotating spindle. The spindle is seldom stopped and there is a risk that you forget that it is rotating when you make changes. Tangled drillings on the tools must be removed and your fingers might get caught. The drillings are often very long and easily catch to your clothes.

The work to correct disturbances is mostly unplanned and carried out under perceived time-stress, thereby increasing the injury risk. It may be a question of correcting a bushing while the drilling is continued, or flying drillings or chips when you change tools, as there may be chips in the drill which fly about when you are cleaning another hole with compressed air.

Horizontal boring machine

The horizontal boring machine is a combined drilling and milling cutter machine which can handle very big work-pieces for a number of operations. It is used for drilling and milling of big details and has a movable workbench on which the work-piece is fastened. The spindle is horizontal and allows the use of several different tools.

This machine has considerable force and the consequences are serious in case of accidents. There are many possible risks of getting jammed or caught between the bench and stationary parts. The surfaces of the machine and the workbench are large and you may easily enter the risk zone without being aware of the risks. The construction is normally open and operations take place near the spindle, for instance when adjusting the tool, or when you are leaning over the tool to follow the operation and risk to have your clothes caught by moving parts. There is also a risk to be hit by chips or drillings or to sustain cuts from long and tangled drillings.

Lathe

The lathe is a multi-purpose machine and is commonly used in the tooling of cylindrical details. It can handle various turning operations and is suitable for long work-pieces which can be fastened between the spindle and the face plate. The turning lathe has a vertical spindle with a chuck where the work-piece is fastened. The chuck may be both manual and hydraulic. Longer series are usually operated in NC machines.

Working with a lathe involves a number of risks for the operator:

- by starting the spindle when the chuck is still in the spindle,
- be starting the spindle before the work-piece is properly fastened,
- getting cut or jammed when changing tools while the spindle is moving, by stopping the chuck manually or by removing chips when turning the inside of a piece,
- hit by splinters due to wrong adjustment or feeding of tools into the chuck,
- the cutting edge catching in the work-piece if the edge is not properly adjusted (too high or too low),
- pressing the wrong button and start the spindle jogging instead of releasing the chuck,
- accidentally moving the start lever and start the spindle,
- accidentally releasing the work-piece by moving the lever of the hydraulic chuck, or because air pressure is low due to a broken hydraulic hose.

Vertical boring and turning mill

This machine is suited for turning heavy work-pieces with a large diameter in relation to their length, eg. ball bearing rings. The machine has a large, horizontally rotating workbench which is sometimes possible to revolve vertically. Big pieces are tooled in small series. There is often a lot of drillings and chips.

The strong forces involved may lead to serious accidents. There is a risk that the work-piece is unfastened from the rotating bench when the machine is in operation. There are risks of being jammed when you are cleaning up around the rotating bench, as well as when removing drillings and chips. A faulty programme may give the wrong signal or accidentally start some functions, eg. automatic change of tool or moving the bench.

Milling machine

The horizontal milling machine is the most common milling machine, with a rotating tool and the feeding rectilinear towards the work-piece. There are several types of milling machines, eg. for single, vertical, long, universal and tool milling.

There is a risk of jamming your fingers between the bench and various parts when adjusting the machine, as well as when fastening or unfastening tools, or if your hand slips when your are grinding on the workbench. There is also a risk of being injured by pieces of a broken cutter or from spattering chips, or sustaining cut wounds from handling the sharp tools.

Grinding machine

There are several types of grinding machines, constructed for different applications:

A *circular grinding machine* works on circular sections with a final measure of strictly defined tolerance. It makes both internal and external grinding with a surface of good evenness.

A *surface grinding machine* has a loosely attached grinding disk with a hard and sharp grinding matter. The contact surface between work-piece and grinding disk is larger than in circular grinding. The feeding table may be rectangular or rotating and horizontally movable. This machine has a great capacity and gives good surface evenness and quality.

An *internal cylindrical grinding machine* has exchangeable spindles to allow the biggest possible diameter of the spindle. The feeding movement of the grinding disk may be axial as well as radial.

A *tool and cutter grinding machine carries* out grinding of tools with several edges, eg. mill cutters, reamers and taps. The machine has a revolving table and a spindle movable in many directions and grinds with great precision and stability.

A common risk with circular grinding is that the grinding disk may break if the magnetic bench can not hold the work-piece or if the disk hits some other detail outside the bench. Other persons near the machine might be exposed to risk since the grinding machine is often left running with tools attached but without being monitored, in order to be kept warm for the next phase of an operation, which gives maximum precision. There is also a risk of getting small splinters in your eyes, as you often have to watch the work-piece closely to control quality.

IMPROVED BRAKING AND EMERGENCY BRAKING

In 1994 the Swedish Institute of Production Engineering Research, funded by the Labour Market Insurances, started a development project to assess the most suitable option to improve the braking and emergency stop capabilities of rotating action machines. Additional factors, like the start/stop functions, design of controls, spindles, jigs, fixtures and chucks were considered secondary to the primary aim of reducing the inertia rotation and improve the quick-stop braking in machines of these types. This priority decision was taken with a view to the average long life and risk exposure of these machines and the estimated prevention efficiency of this measure over time.

An initial assessment concluded that the development or application of an electro-dynamic motor braking device would be the most suitable solution.

Different forms of braking (Plachetka, 1986)

The friction brakes, traditionally used in most motors, are maneuvered manually or by electro-magnetic, hydraulic or pneumatic devices. An advantage of friction brakes is that the motor when stopped can not start again by itself. However, they have several disadvantages; they wear out, they produce dust, they cause noise, and they are sensitive to disturbances when worn down. To avoid these effects, and to improve effectiveness in braking, workshops have started to use electric braking devices. The most important methods are counter-current and direct-current braking. The direct-current braking is somewhat more expensive than the counter-current method, but it means less wear of the rotor.

Counter-current braking has been the most common of the electric braking methods. Two of the three mains connections of the stator winding are inversed and create a counteractive momentum which stops the motor. If the motor is not disconnected in time it will start running in the opposite direction, and to avoid that over-run controls and frequency relays are used. An advantage with the counter-current braking is that the electric construction is simple. The disadvantages are that the momentum of braking is high, the adjustment of the momentum, which is made by resistance, is complicated, the loss of effect is great and the strains on the starting equipment are high.

To avoid the high losses of effect, direct-current braking is the most convenient method. This braking process is started by disconnecting the stator winding from the three phase supply and feed it with direct current from two or three brushes. This creates a static field in the motor and the rotating rotor induces an alternating current. The result will be a current which brings about a strong braking with no bumps; a resistor is attached to the rotor circuit in order to limit the braking current.

In the initial phase of the braking, when the rotor is still moving at full speed, the brush current is approximately as high as the resting current of the rotor. During the braking process of the moving mass an amount of heat is released relative to the kinetic energy. This amount of energy is a mere third of the amount of energy released when using a counter-current device. If the current is produced by phase angle control via a thyristor, it can be continuously controlled and thus the braking power can be adjusted to the actual need.

The delay in braking should be between 100 ms and 3 s depending on the choice of motor size and winding. Frequent braking may lead to thermal overload and therefore some devices operate two different braking options; one brakes the motor softly within the recommended time-frame, the other is used for emergency braking with a maximum effect.

IMPLEMENTATION AND PRACTICAL CONSIDERATIONS

Faced with a decision to implement effective braking of a rotation action machine, and thereby improve operational safety, the employer basically has three options:

- to retrofit additional brakes eg. spring-loaded friction brakes, disk brakes or magnetic brakes;
- to retrofit a frequency transformer, eg. movitrac;
- to exchange the motor for a new motor with built-in brakes.

An inventory of the market shows that there is a relatively great number of motor braking devices available. Prices start from around US$ 250 and increase depending on motor size and rating. However, the price of a pedestal or radial arm drilling machine or a lathe is such that the buyer often is sensitive to extra costs such as buying and installing a motor-braking device. Thus a cheap solution will be demanded.

The main purpose of installing a motor-braking device is to be able to quickly stop rotating parts when production is discontinued. Thereby you decrease the time of exposure for operations close to rotating tools and work-pieces. It is important to separate the normal procedure of “soft” braking from the protective emergency stop with maximum braking momentum, with great mechanical loads on the motor and gearbox.

Such loads must be accepted in the emergency cases but should be avoided in normal operations. An acceptable motor-braking device should be equipped to perform both types of braking.

A problem with the existing braking modules (for retro-fit) is that they may not fulfil the high demands of redundance in terms of fault resistance which is normally demanded from a safety device. A simple component failure or disturbance in the braking module should not lead to a loss of braking effect or to start failure. These devices must also comply with demands for a high cycle time (frequent braking per time unit considering the heat generated), minimum delay of connection, and automatically or manually adjustable braking time.

Adding to the cost of the braking device itself will be the cost of selecting the type of device, mechanical adaption, electric connection, operational adjustments and inspection.

Of the three options above only one appears to be fully acceptable, taking all factors in relation to safety, productivity, environment, and costs into consideration. The average life span of rotating action machines is long, and a complete upgrade to a more energy-efficient and environmentally friendly motor can often be argued from both a productivity and an energy consumption point of view. When the indisputable safety aspects are also taken into consideration, there is a strong argument for this type of upgrade.

It is also easier to install a complete motor, as no mechanical adaption is needed and the buyers own electrician can make the necessary connections. Choosing a substitute motor is a less complicated procedure than choosing a separate braking-module for retro-fit. Motor and braking device will be one integrated unit which comes with the performance data and product guarantees from the motor manufacturer.

Thus, even if a new electric motor with integrated braking functions cost US$ 600.-, the total cost of a complete motor upgrade would still be comparable to the cost associated with retro-fitting a braking device to the old motor.

CONCLUSION

A campaign directed at companies using rotating action machines should contain detailed information on the different types of machines associated with specific risks in relation to rotating tools or work-pieces, the typical tasks associated with traumatic injury, and the cost-benefit discussion related to the suggested motor upgrade.

The cost-benefit analyses for individual companies and machine types will of course vary depending on many factors, but a number of practical examples from different types of production and applications can be made.

To facilitate the necessary investment of the US$ 600.- to US$ 1,250.-, which may be the total cost of a complete motor upgrade per machine, the workers’ compensation insurance should consider a loan/part-subsidy scheme, similar to subsidy schemes applied to the retro-fitting of roll-over protection on tractors (Victorian Workcover Authority, 1997).

In Sweden alone, such targeted measures may reduce substantially the seemingly continuous annual harvest of 70 - 100 severely impairing injuries associated with rotating action machines in the metalworking and engineering industry.

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