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SAFETY STUDY OF OSHA'S EXPERIMENTAL VARIANCE ON SELF-TRIPPING OF POWER PRESSES

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PHASE II - Volume 1

A Safety Engineering Assessment of the Light Curtain -- Power Press System

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Abstract

Work which requires hand feeding of workpieces between the dies of a mechanical power press creates amputation risks for press workers. An electro-optical device which permits rapid hand feeding of parts into a press and allows the press control to recognize when a hand is clear of the danger area and automatically stroke is discussed. Although the system is quite attractive in a productivity sense, there are safety concerns which must be considered. This paper discusses considerations for assessing the safety of automatically activated, hand fed machines. The quality, reliability and safety of individual system components is considered. The system integration of these components is given major consideration. The issue of liability is also discussed.

1. INTRODUCTION

1.1. THE ENGINEERING PROBLEM - WHAT ARE THE SAFE PERFORMANCE LIMITS OF THE POWER PRESS AND AUXILIARY UNITS SYSTEM (THE "MACHINE" SYSTEM)

When used in manufacturing, the mechanical power press is inherently a dangerous machine. If an operator places his hands or body between the descending slide and the bottom die there is some risk of being injured or even killed. There are many reasons, both normal and unusual, for a worker being at the danger point. Therefore, in civilized countries there are laws prescribing safeguards for protecting power press operators. Particular hazards arise when the operation requires the operator to place his (her) hand(s) in the die to insert or remove the workpiece*. This article discusses quality, safety, and reliability considerations on one proposed, but currently restricted method for safeguarding and automatic cycling presses which are hand fed. Quality, safety, and reliability are considered both for individual components of the system and for the integrated system.

* The attitudes of U.S. press manufacturers to the question of "hands in the die" differ. While some build presses with two-hand controls that make it possible for the operator to put his (her) hands in the die, others are adamantly opposed to this situation [Ref. 1].

1.2. THE "MACHINE" SYSTEM FOR TWO TYPES OF SAFETY/ACTIVATION DEVICES

1.2.1. Two-Hand Controls

Many devices that have been developed over the years to reduce the risk of injury. The two-button safeguarding system has been a principal means for injury control. The basic concept of this mode of press safeguarding is that the operator must use both hands "concurrently" to effect slide descent [Ref. 2]. What does "concurrent" mean in this context? According to American National Standard ANSI B11.1-1982 that refers to the safety of mechanical power presses [Ref. 3], "specifically, as applied to the operation of run buttons or inch controls, the use of the word "concurrent" means that the clutch will be activated after each hand of the operator is holding a control in the operated position.

The use of the word "concurrent" is intended to exclude any inference that a simultaneous moment of actuation must exist between the operations of the individual hand controls."

Many two-hand controls designed to satisfy the "concurrency" requirement as its was understood were found to be easily circumvented by holding one button pressed down by a load or bar, so that the press could be activated by one hand only, thus defeating the safety purpose of these controls. Today two-hand controls can be so designed that the press will be activated only if the two buttons are pressed within no more than 0.5 seconds of each other. Such stipulation is made in, e.g., the West German standards [Ref. 4].

Other safety problems with two-hand controls involve accidents caused to

or by persons other than the operator, sometimes the operator's helper, or foreman. It is worth noting that in a recent German machine safety handbook (written in 1975) [Ref. 5] it is stated: "Two-hand actuation of an eccentric press. This solution is suited for single stroke operation only. The condition is that only one person works on the press. Better are safety measures such as guards, light curtains etc." The stipulation of the 0.5 second limit between the actions of the two-hand controls is repeated in this handbook [Ref. 6].

1.2.2. Self-Tripping Light Curtains

In 1953 there was introduced in West Germany, by the Sick Optik Company, a new device for activating presses. It consisted of a photo-electric light "curtain" in front of the point of operation of the press, and appropriate circuitry. When the operator's hand penetrated the curtain, the press slide stopped, and when the hand was withdrawn, the press slide moved down. This "self-tripping" light curtain was first applied to hydraulic presses and shortly afterward, to mechanical presses. Because of the higher productivity and elimination of the "second person" type hazards, self-tripping light curtains began to be installed on mechanical presses in significant numbers. At the same time, light curtains (of various kinds) and presence sensing devices operating on other physical principles (radio waves, ultrasonics, air jet), all without the self-tripping capability, began to be used as press safety devices in increasing numbers in various countries. Their use is permitted in the U.S. on mechanical power presses if the specifications of OSHA Regulation 1910.217 [Ref. 7] are met. The same regulation, however, explicitly forbids their use for tripping: "The [presence

sensing point of operation] device may not be used as a tripping means to initiate slide motion." This is in contradistinction to the situation in West Germany and Sweden where tripping of the mechanical power presses by means of light curtains has been permitted for years. The German manufacturer who wishes to use this technique must meet the appropriate standards [Ref. 8] elaborated and administered by the Central Association of Industrial Organizations (free translation of Hauptverband der gewerblichen Berufsgenossenschaften, abbreviated as VBG) whose authority is comparable to that of OSHA. However, cases of major violations are reported to the Federal Ministry of Labor; the Swedish standard is the General Machinery Directions No. 29, issued (May 1978) and administered by The Swedish National Board of Occupational Safety and Health [Ref. 9]. Of historical interest is the West German regulation of 1961, which specifies the requisite features of safety curtains, including the stipulation for self-checking [Ref. 10].

1.3. THE CURRENT INTEREST IN USING SELF-TRIPPING

In view of the successful operation of self-tripping light curtains installed on mechanical presses, resulting in better safety and higher productivity than two-hand control, a petition for variance permitting the use of such self-tripping method on an experimental basis was granted to the Interlake Stamping Corporation of Willoughby, Ohio, on August 26, 1976 [Ref. 11]. The present report looks at how the safety of future installations might be confirmed*.

* A number of reliability studies of several light curtains were made in the U.S. and abroad. Since the reports are not in the public domain, they cannot be discussed here [Ref. 12].

When one compares the situation in West Germany and Sweden where self-tripping light curtains systems are permitted with that prevailing in the countries where it is not, the question arises -- why the difference. This was the topic of interest in a research effort carried out by Purdue University and the National Institute for Occupational Safety and Health which concluded that the answer is twofold: (1) assurance in the quality of the individual system components, and (2) assurance that the press with all its subsystems is of acceptable quality. The following calculation should clarify the effect of the quality of one component on the level of the entire system's reliability. Assume that a shop has 40 presses, each working 6000 hours a year. Each press has a work cycle of 5 seconds, i.e., 720 cycles/hour. Also assume that the light curtain has a mean time between dangerous failures of 1600 years, or close to 10,000,000 hours. To calculate the probability of zero accidents, one accident, two accidents, etc., we use the Poisson distribution [Ref. 13] according to which the probability of zero accidents ("reliability") in time t is $e^{-\lambda t}$, of one accident $\lambda t e^{-\lambda t}$, of two accidents $\frac{(\lambda t)^2}{2!} e^{-\lambda t}$ and of n accidents $\frac{(\lambda t)^n}{n!} e^{-\lambda t}$. Here λ is the failure rate of the entire population in failures/year, t is the time in years. In our case $\lambda = (1/1600) \times 40 = (1/40)/\text{year}$, t = 10 years. If the curtain is used for self-tripping, then in ten years the likelihood of no accidents in the entire shop ("safety-reliability") is $R(t) = R(10) = e^{-10/40} = e^{-0.25} = 0.78$ = 78 percent. The likelihood of one accident is $0.25e^{-0.25}$ = 20 percent, and of two or more accidents is the remaining 2 percent. The unsafety seems rather high, even with the

apparently "good" quality of one curtain (10 million hours between dangerous failures). However, if the curtain is not used for tripping, only as an additional safety, and is used, for example, only once an hour on the average, its likelihood to fail while needed (i.e., in one cycle) is 720 times smaller. In such case and if a failure is automatically detected, the likelihood of one dangerous failure in the shop over 10 years becomes 20/720 or less than 0.03 percent, and of more than one, 0.003 percent. This would seem acceptable to the user in question.

However, today's technology permits the construction of light curtains with mean time to unsafe failure fifty million times longer than the figure quoted above. The Sick light curtain that was analyzed in the course of this study has a computed mean time to unsafe failure of 5×10^{15} hours, or a failure rate of $2 \times 10^{-16}/h = 1.2 \times 10^{-12}/year$ assuming a three shift operation (6000 hours a year). The Poisson parameter λt is in this case $1.2 \times 10^{-12} \times 100{,}000 \times 50 = 6 \times 10^{-6}$. Based on this, the probability of no accidents over 50 years in the <u>entire population</u> of 100,000 presses is $R(50) = e^{-0.000006} = 0.999994 = 99.9994$ percent! The probability of one accident is $6 \times 10^{-6} = 0.000006 = 0.0006$ percent, of two accidents 1.8×10^{-11}, of three 3.6×10^{-17}, of four or more is almost inexpressibly small. The combined probability of all possible numbers of accidents is still an incredibly small 6×10^{-6}, or six in 1,000,000 (equal to probability of one accident because of rounding error). For an accident to occur in the entire population of 100,000 presses with a probability close to 1, one would have to wait not 50 but half a million years!

The above calculation can serve as a guide for the lowest value of the computed mean time to unsafe failure of a light curtain that can be accepted for self-tripping purposes. If it is assumed that the above indicated failure probabilities can be safely increased by a factor X, the acceptable mean time to unsafe failure may be reduced by the same factor X. (This applies to probabilities of zero and one failure, but if in the above example λt is increased even 1000 times, the probabilities of two and more failures are still vanishingly small and do not practically violate the linearity assumption.)

2. THE SAFETY OF SYSTEM COMPONENTS

2.1. LIGHT CURTAINS

There is currently a dependence by the system user on the quality control and reliability capabilities of light curtain makers. Clearly one only should install highest quality, long proven curtains.

The Report of Phase I provides detailed explanation of an independent reliability analysis that was made for the Sick Light Curtains LVU200 and LVU300. The salient points are recapitulated below. i. The functioning of the entire device is "unraveled" from the circuit diagrams. Manufacturers' claims with respect to the function of the various components are verified (for example, self-checking). ii. All possible failure paths (minimal cut sets) are identified and checked for criticality, i.e., safety. Ideally every possible failure mode should result in press controls deactivation, but if some failures cannot be

made safe, the system should be so designed that their probability is extremely small (e.g., a situation requiring the joint failure within a few milliseconds of two highly reliable components). iii. The equation (in terms of states) of the union of the unsafe cut sets is produced. iv. The probability of the union in (iii) is computed using handbook values of element failure rates. The obtained value is the probability of unsafe failure of the device. The conventional reliability (probability of al failures, safe and unsafe) is computed in the assumption that every element is needed for the device to work, i.e., using the series model. Here, too, handbook data for element failure rates are used.

Such analysis must be done by persons with knowledge of electrical and electronic engineering, and of mathematical theory of reliability.

It must be realized that mathematical analysis of the reliability of a presence sensing device relates to its design, but says nothing about its construction and manufacturing quality. A light curtain works in a difficult environment, is exposed to shocks and vibrations, accumulation of dust, possibly oil spills and other shop hazards. To assess its viability under these conditions, the actual light curtain has to be carefully examined and life-tested under simulated real life conditions. Reputable builders conduct these tests continually. This presents an opportunity for self-certification, but the various facets of such an approach will not be discussed here. Independent testing laboratories could be engaged to conduct such tests, if so desired. With regard to industrial experiments, these should be conducted with light curtains that have a proven record of viability -- and dependability.

The Report of Phase I concerns itself with the mathematical analysis of the internal structure of the light curtains in question. Clearly there are numerous more qualitative safety aspects that must be considered. For example, is the curtain immune to the effect of stray light, electromagnetic radiation in non-light parts of the spectrum, vibrations, leakage currents and many others. These aspects are very well covered in the so-called "Boeing Study" [Ref. 14] and will not be discussed here.

A second important consideration is the simple reliability of the curtain. It should be high enough so that there is no incentive to circumvent it. Judging by the present acceptance of industrial equipment, 500 hours for mean time between failures should be considered adequate. It must be borne in mind that the exceptional safety of high quality light curtains is attained through the incorporation of self-testing features, which requires additional components, causing a higher cumulative rate of failure.

It must be admitted that the choice of 500 hours as the computed mean time to failure (or between failures) is somewhat, though not entirely, arbitrary. Credible values of actual mean time to failure of complete systems, especially such with not only electronic but also electrical (transformers) and electromechanical (relays, motors) components are practically impossible to obtain from literature or by word of mouth. Handbooks such as the one used [Ref. 15] in Phase I of this study give in most cases the average value of the failure rate taken over a portion of the "reliability bath tub curve", and generally do not indicate how much can be gained by "burning-in" electronic components.

Electromechanical components are usually much too expensive for large scale life testing so that the number of data points, and hence the confidence, are often not very high. Still, the experience gained over the last forty years indicates that when product quality and good design are maintained, the computed reliability is an excellent reference parameter. With regard to the chosen value of 500 hours, it is between the 550 hours reported for diesel engines [Ref. 16] and 400 hours for modern robots [30]. It must be realized that mean time to failure is not the only reliability parameter; mean time to repair is equally important. If an item can be repaired within a day (say the "repair person" can be on location and do the repair within 24 hours), then the total downtime for one shift operation is only 1.6 percent which is very low for the type of manufacturing concerned.

2.2. TWO HAND OR PALM BUTTONS

The failure modes for palm buttons include: shorting of contacts by metallic chips or debris; ease in unauthorized or authorized wiring across buttons; button pressed by another person than the person being protected; button sticks or is held in the closed position after an initial depression.

The major preventive measures for these failure modes are in the OSHA standards for anti-repeat and single stroke devices to be used as part of palm button run systems; and for supervision and training of operators against the risk of unauthorized redesign of the machine system.

2.3. THE CLUTCH AND BRAKE

There are three failure conditions which must be considered and avoided if possible; (1) destructive failure; (2) wear; and (3) environmental operating changes. To be suited for self-tripping, the press must be equipped with a part revolution clutch and brake, be capable of stopping the slide in no more than 200 milliseconds under worst conditions, and be so constructed as to prevent entry of the operator past the light curtain.

Part revolution clutch and brake insure that the crankshaft can be disconnected from the flywheel, and that the remaining moving parts of the press, especially the slide, can be stopped at any position of the downstroke travel. Regulations specifying the clutch and the brake are the same as for two-hand control activated mechanical presses [Ref. 17] with presence sensing point of operation devices. (The statements concerning full revolution positive clutches and guards and pullouts do not apply, of course). The brake is clearly a vital component in the sense of operator safety. Reputable press builders in the U.S. and abroad make or buy excellent brakes and clutches. The safe performance criteria which apply to machine tool brakes is that the brake be sized so that it will stop the machine quickly, it will engage with a torque below the safe design limits of the crankshaft, it wears at a rate compatible with reasonable maintenance cycles, and it is capable of resisting destructive failure under specified overload conditions. The most suitable for presses with presence sensing devices are integral brake-clutch units. They offer maximum torque and minimum moment of inertia, as well as simultaneous clutch disengagement and brake

activation. These three features are important for minimizing press (actually slide system) stopping time and for mechanical reliability.

The stopping time should be short enough to provide reasonable safety distance (from the light curtain to the press point of operation) based on hand speed of 2.5 m/s. A distance in excess of 20 inches makes operator's work uncomfortable, difficult or impossible. For this reason the stopping time should not exceed 200 milliseconds, under worst permissible conditions, which means with worn brake and lowest coefficient of brake lining -- brake disc friction (which is a function of wear and operating temperature).

Stopping time value per se is not stated in OSHA Regulation 1910.217, but 200 ms maximum is the value mentioned in the Boeing study, with the comment that it is attainable in modern mechanical power presses [Ref. 14]. According to a statement made by the representative of a leading U.S. press builder [Ref. 18], presses built in the U.S. after 1971 have a stopping time of 0.1 sec. Adding the wear factor (30 percent) and light curtain response [Ref. 14] of, say, 25 ms. the value of .200 ms as the maximum permissible is reasonable and attainable. It is conceivable that in the future it will prove desirable to have shorter stopping times. Since these will produce higher impact loads in press components and may cause press tipping, the problem should be investigated, preferably jointly with one or more press builders.

Presses with weaker brakes may have excessively long stopping times. The only permissible modification should be the installation of a modern <u>integrated</u> (one unit -- one air line) brake-clutch system (and the

upgrading of all other elements of the air-valve -- clutch brake system), to be executed by the press builder or a recognized expert.

As the press is down for modernization, opportunity is available for inspecting the press frame and crankshaft for possible cracks caused by repeated overloading (especially jamming) over years of operation, and for executing the necessary repairs [Ref. 19].

Whatever the particular design of the brake or the clutch, certain features must be provided. The brake must be selfacting, actuated by several compression springs. It must exert adequate braking torque and not jam even if one of the springs breaks. Also, it must be protected from entry of oil or other contaminants. The clutch must be of friction type (dry or wet, single or multiple-disc) and must not be able to seize-up. It is to be actuated by air pressure, and become free when the air is vented.

2.4. REDUNDANT BRAKES OR AUXILLIARY BRAKES

Addition of an auxiliary brake should not be allowed, even though German standards require and British regulations permit this, because it is difficult to insure simultaneous operation of two brakes. The same applies to systems in which the brake and the clutch are physically separated.

The stipulation of the German Safety Regulation 11.062 [Ref. 8] that for the case of "hands in the die" mode of operation the press must be provided with a back-up brake or other slide stopping device such as a jamming block has caused no small amount of confusion. Swedish

regulations make no such stipulation, and in personal communications Swedish experts consider the German auxiliary brake requirement totally unnecessary. The same opinion has been privately expressed by German experts. According to them, if the standard were written today, the auxiliary brake or stopping device would not be even mentioned.

The German standard 11.062 speaks about "brake failure". The explanation offered privately is that in days past (35 years ago) brakes were made of "inferior materials and broke", which would explain a sudden failure. We believe that the actual situation at that time was somewhat different. Old presses had stopping times much longer than is permitted by the safety considerations of two-hand controls. As such controls began to be installed, brakes apparently were made more "powerful" by inserting stiffer springs, which greatly increased the load on the lining (and even the disc), causing fracture in operation. But eventually new brake designs appeared, and today high quality German disc brakes are as good as those made in the U.S. This can be verified by reviewing the catalogs of leading makes in both countries, e.g. [Refs. 20 and 21]. In other words, the German stipulation is an anachronism which should be recognized as such and discounted.

2.5. THE SOLENOID AIR VALVE

Another critical component is the solenoid actuated air valve for the clutch. OSHA Regulation 1910.217 stipulates a redundant self-checking device (though not using exactly these words) for controls built and installed after August 31, 1971. Several makes of such valves are on the market. They are pneumatically and electrically redundant. Whatever the malfunction (except for outright sabotage), the air is

exhausted (which activates the brake) and the valve is then disabled, so that the clutch cannot be re-activated. Clear explanation of the functioning of such a valve is given in, e.g., Ref. 22.

The quality of the air supplied to the valve and clutch is very important. It should be processed as required by the valve and clutch manufacturers, which in most cases means dried, filtered and possibly mixed with oil. The filter size is very important; if pores are too large, valve may seize. An attempt was made to obtain, from a well-known valve maker, data about the tolerances to which valves are made so as to assess the appropriate filter fineness, but unfortunately the request was denied on the grounds that the information was proprietary.

In modern presses it takes twice as long for the valve to react and the air to exhaust from the clutch chamber as for the brake to stop the crankshaft [Ref. 23]. For this reason the quantity of air let into the clutch chamber must be carefully controlled, i.e., the air pressure must be controlled. Excessive air pressure increases the stopping time. Not only should a pressure regulator be employed, but the set points for the pressure limits should be monitored, and the press controls become deactivated if they are exceeded. The air pressure normally used is at 45 to 60 psig, depending upon clutch make. Pressure control within 10 percent will maintain air exhaust time within similar limits. However, the press stopping time is the decisive parameter and should be measured for the upper pressure limit.

2.6. BRAKE MONITORS

The quality of the materials, design and manufacture of modern brakes and clutches built by reputable firms ensures that these systems will not fail suddenly. Their function deteriorates gradually, because of wear, with the exception of brake springs which may break in fatigue, but not all at the same time. To detect this deterioration OSHA 1910.217 stipulates the presence of brake monitor. This device consists of a cam mounted on the crankshaft, or more frequently on a shaft connected with a chain drive to the crankshaft, and a limit switch that is depressed when the cam rotates past it. After the brake has been activated, the crankshaft should stop rotating before the cam reaches the limit switch. If it does reach and depress it, the inference is that the brake is too "weak" and the press stopping time is in excess of the upper limit. The signal produced by the limit switch deactivates press controls. The position of the switch relative to the vertical axis of the crankshaft can be adjusted to obtain the correct setting. This setting is, of course, extremely important for operator safety. Clearly, if the brake is too weak, it has to be repaired, which generally means relined, possibly the springs replaced. Then the stopping time has to be measured with a special instrument, and the limit switch reset, allowing for some extension (usually 20 percent) of braking time due to permissible lining wear and brake surfaces contamination. From the obtained crankshaft angular velocity -- time characteristic of the press being braked one calculates the increase in the crankshaft stopping angle corresponding to the allowable increase in the stopping time. Details of such calculation are given in Ref. 24.

Sometimes the crankshaft angles have to be converted to slide position. To simplify the required calculations one can use special slide rules provided by light curtain builders (e.g., Sick Optik Elektronik).

2.7. ADDITIONAL GUARDING

If the press is large enough for the operator to walk-in past the protected plane and fully enter the space under the slide without any part of his (her) body interrupting the light curtain beam, protective barriers are needed. The German safety rules forbid the use of presence sensing devices if the table of the press or a guard in front of it is lower than 750 mm above the floor [Ref. 25]. The Swedish safety rules allow a photo-electric device in these conditions as a guard only provided additional control devices are available [Ref. 9].

If a small press is used then the combination of coverage by barrier guards and safety devices should prevent unprotected entry into the point of operation.

2.8. CONTROL RELIABILITY AND CAM SETTING

The OSHA Regulation 1910.217 covers the electric controls of mechanical power presses. Modern two-hand controls have all the features needed to activate the press by a self-tripping light curtain. This includes "cam muting", i.e., deactivation of the slide emergency stopping function in upstroke. Reliability of relays can be greatly enhanced by using such with captivated contacts. These contacts must move together, so that, e.g., if one welds, the entire relay will not open which will deactivate the controls.

To sum up this section one can state that a reasonably modern, properly maintained press, equipped with modern two-hand controls, and meeting all the appropriate OSHA rules can be converted to self-tripping with a suitable light curtain provided its stopping time is no more than 200 ms.

3. SYSTEM INTEGRATION

3.1. INSTALLATION

The fact that each individual components of the light curtain-press system is safe does not per se guarantee that the integrated system will work or work safely. One could cite innumerable examples of incorrect assembly of parts resulting in a faulty unit. Wrong electrical connections, loose connec..ons, damage during assembly, constriction of fluid passages, back-to-front installation, misalignment of bearings, gears, optical components and a myriad of other sins are the result of careless or incompetent work, which ends up in producing a malfunctioning or a nonfunctioning product. Light curtain-press systems are no exemption and attempts in their integration undertaken by incompetent individuals may result in nonfunctioning and conceivably even unsafe systems. There is no way of prescribing the specific rules for all possible cases of curtain-press integration. It is therefore absolutely essential that self-tripping system integration be performed by the press builder or by an expert trained by the light curtain manufacturer.

The installation procedure [Ref. 26] begins with a survey of the press to be equipped with the light curtain, and if the press is found suitable, the appropriate light curtain model is selected. In the course of the installation process there are several steps, the first being the determination of the press stopping time, by measurement or otherwise. Then the safety distance from the light curtain to the nearest possible die closure (pinch point) is calculated. As the exact location of the light curtain on the press is being determined, a check is made if additional guarding is needed. Such guarding is essential if there is a possibility of reaching into the danger zone over, under, or behind (from the side) the curtain. Figures 1 to 4, provided courtesy of Sick Optik Electronik Inc. illustrate the danger of leaving such open spaces between the light curtain and the press. These additional guards are in the form of bars, screens, grids, or other solid obstacles. They must be firmly attached so that removal is difficult and preferably provided with electric interlocks with machine controls. Sometimes additional light curtains are used as such guards. Much more detailed description of the installation procedures is provided in the manuals published by reputable light curtain manufacturers, for example [Ref. 26]. The acceptance procedure is also described there.

It is proposed here that in the formula of the safety distance, the hand speed constant -- 63 inches/second -- , be increased to 100 inches/second (2.5 m/s). The latter agrees with the Swedish safety regulations [Ref. 9], in which the speed of 2.5 m/s is specified for handling small parts in "fast rhythmical work", and 1.6 m/s (63 in/s) for handling "large, awkward" parts. A recommendation to change the

hand speed constant in OSHA Regulation from 63 in/s to 2.5 m/s is also made in the Boeing study [Ref. 14].

3.2. INSPECTION AND MONITORING

Not only the light curtain system has to be regularly inspected, but the other press systems as well, following the builder's instructions.

One of the criteria for selecting a make of self-tripping light curtain should be the ease with which an installed curtain with its press and guards can be regularly inspected. The individual performing the inspection should be very familiar with the inspection procedures developed by the curtain manufacturer. Power presses in general should be checked for safety at least once a day (or at the beginning of each shift) [Ref. 27], and this includes checking the light curtain system. The curtain manufacturer should provide clear instructions for the daily check, such as, for example in [Ref. 28]. These instructions should be permanently attached to the optical unit, be indelibly printed on metal and be clearly legible.

Equally important are instructions for regular maintenance and periodic (yearly or more frequent) inspections. Because of the relative complexity of the light curtain system, persons conducting the periodic inspection should be trained by the curtain manufacturer. Alternatively, the manufacturer may be contracted to conduct periodic inspection.

The silencer of the clutch exhaust may build up dirt and impede air flow. An air line may be pinched accidentally, resulting in the slowing

down of press start, etc., etc.

3.3. SITUATION IN OTHER COUNTRIES

As indicated above, self-tripping of mechanical power presses with light curtains is permitted in Sweden and West Germany. It is known to be forbidden in Japan and Taiwan. The situation in the United Kingdom is not clear to us at the moment -- there is a very detailed regulation specifying the performance and technical characteristics of light curtains [Ref. 29] but their use for self-tripping is not mentioned one way or another.

3.4. RESPONSIBILITY

A major concern for anyone associated with the development of an industrial machine system is the ever-increasing risk of litigation on behalf of injured workers to get punitive compensation for injuries suffered in the use of the product. The question exists of responsibility to test a system for possible hazards, to warn users of potentially worst effects of use or of misuse, and to ensure that precautions have been taken against manufacturing defect. Who should be liable for what? It might appear intuitive that vis-a-vis the operator, the user has the prime responsibility for safety and that on his part, the user would expect the press builder to be responsible for the press, the curtain manufacture for the curtain, and whoever installed the curtain, for the proper installation. Unfortunately these intuitive responsibilities do not always apply in adversarial contests to establish liability and to gain maximum compensation. The benefits to be gained in the use of a more efficient production system are enjoyed

by the employer using the system, while the risks of system failure are borne by the injured worker and by the designer who can afford to compensate for the injury.

4. REFERENCES

1. In a letter sent by the Assistant to the President of a major U.S. press builder to the Purdue investigators it is stated that: "(the company's name) takes a strong stand for 'Hands out of the Die' operation of Mechanical Power Presses and is firmly opposed to an operator being required to place his or her 'hands in the die'," 17 February 1982.

2. OSHA Regulation 1910.217 Mechanical power presses, (b)-(7)-(iv)-(a). Code of Federal Regulations, Title 29, Chapter XVII, Occupational Safety and Health Administration, p. 459.

3. American National Standards for Machine Tools - Mechanical Power Presses - Safety Requirements for Construction, Care, and Use. ANSI-B11.1-1982. Approved January 22, 1982. American National Standards Institute, Inc., New York.

4. Sicherheitsregeln fur Steuerungen an kraftbetriebenen Pressen der Metallbearbeitung. Hauptverband der gewerblichen Berufsgenossenschaften (VBG), Zentralstelle fur Unfallverhutung, Fachauschuss "Eisen und Metall III", (Safety Rules for Controls of Power Presses in Metal Working. Central Association of Industrial Organizations. Accident Prevention Center, Technical Committee "Iron and Metal III". Published January 1972, p. 2.

5. Randant, Siegfried and Defren, Werner: Sicherheitstechnik in Maschinenbau (Safety in Machine Construction), Walter Stutz, Munich, (ISBN 3-87798-007-4), (no publication date), p. 119, caption to Fig. 112.

6. Ibid, pp. 161-2.

7. OSHA Regulation 1910.217 Mechanical power presses, (b)-(14)-(c)-(g)-(iii)-(b). Code of Federal Regulations, Title 29, Chapter XVII, Occupational Safety and Health Administration, p. 462.

8. The prime standard is "Accident Prevention Regulation 11.062 Eccentric and Related Presses (VBG 7n5.1)". The first version was published 1 April 1957, the current (fifth) on 1 April 1981. This standard makes references to various regulations pertaining to specific details, such as "ZH 1/456 Safety Regulations for Two-Hand Controls on Power Presses in Metalworking" and "ZH 1/281 Safety Regulations for Non-Contact Safety Devices on Power Presses in

Metalworking", and other standards issued by, for example, DIN or VDE (German Industrial Standards Association or Organization of German Electrical Engineers), where relevant.

9. General Machinery Directions No. 29, The Swedish National Board of Occupational Safety and Health, Stockholm, May 1978. Published in Swedish and translated into several languages including English. The Swedish version is the authoritative.

10. VBG 7,5.4, Section 4, Paragraph 2, No. 10, "Eccentric Presses and Related Presses" (Translated as NIOSH Document No. 790039, February 1, 1980).

11. Federal Register Document 76-25472.

12. Readers interested in these studies may wish to contact Sick Optik Elektronik, Inc., 2059 White Bear Avenue, St. Paul, Minnesota 55109.

13. There are many excellent books on reliability. The following is one of them: M.L. Shooman, "Probabilistic Reliability, An Engineering Approach", McGraw-Hill, New York, 1968.

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15. Military Standardization Handbook: Reliability Prediction of Electronic Equipment. MIL-HDBK-217C, 9 April 1979.

16. Willie Hammer: "Product Safety Management and Engineering", Prentice-Hall, 1980, quoting Nonelectronic Reliability Notebook, Rome Air Development Center, Griffin Air Force Base, New York, January 1975 (AD/A-005657).

17. OSHA Regulations 1910.217 Mechanical power presses, (a) to (c) inclusive. Code of Federal Regulations, Title 29, Chapter XVII, Occupational Safety and Health Administration, pp. 458-464.

18. Meeting of the Purdue research team with representatives of U.S. press builders, NIOSH and OSHA, Purdue University, July 28, 1982.

19. Robert R. Campbell: "How to Diagnose an Ailing Press", Metal Stamping, August 1978, reprinted in "Understanding Presses and Press Operations", Editor Donald F. Wilhelm, Society of Manufacturing Engineers, 1981.

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21. For example clutch-brake catalogs of E.W. BLISS, Division of Gulf+Western Manufacturing Company, Southfield, Michigan.

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23. Mechanical Power Press Safety Engineering Guide, NIOSH Contract 210-75-0042, WILCO Inc., Stillwater, Minnesota, September 1976, p. C-22.

24. Ibid, pp. C-9-13.

25. Unfallverhutungsforschrift 11.062 Exzenter und verwandte Pressen (Safety rule 11.062 Eccentric and Related Presses) VBG7n5.1, 1 April 1957, modified 1 April 1981, p. 11.

26. Sick Optik-Electronik, Technical Description, Installation Manual, Troubleshooting List, and Information Packet Checklist, all for LVU Safety Light curtains, 108pp.

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30. J.F. Engleberger: "Robotics in Practice", AMACOM, 1980.

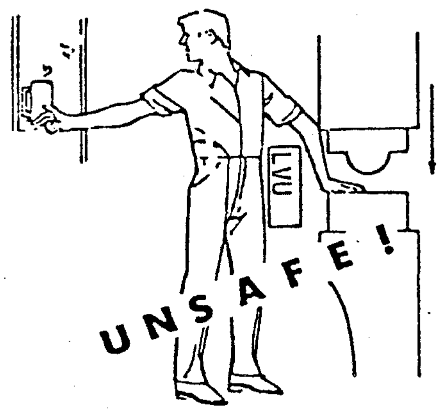

Fig. 1

Reach-over If the top of the safeguarded area is less than 6 feet above the floor and it is possible to reach over the light curtain into the dangerous area, supplemental guarding is necessary above the light curtain. If the top of the safeguarded area is more than 6 feet above the floor, supplemental guarding may not be needed.

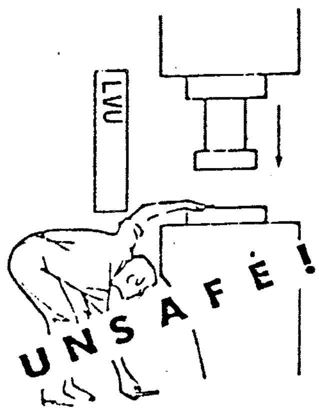

Fig. 2

Reach-under If it is possible to reach into the dangerous area from under the safeguarded area, supplemental guarding is needed below the light curtain. The maximum unguarded opening must be less than 2 inches.

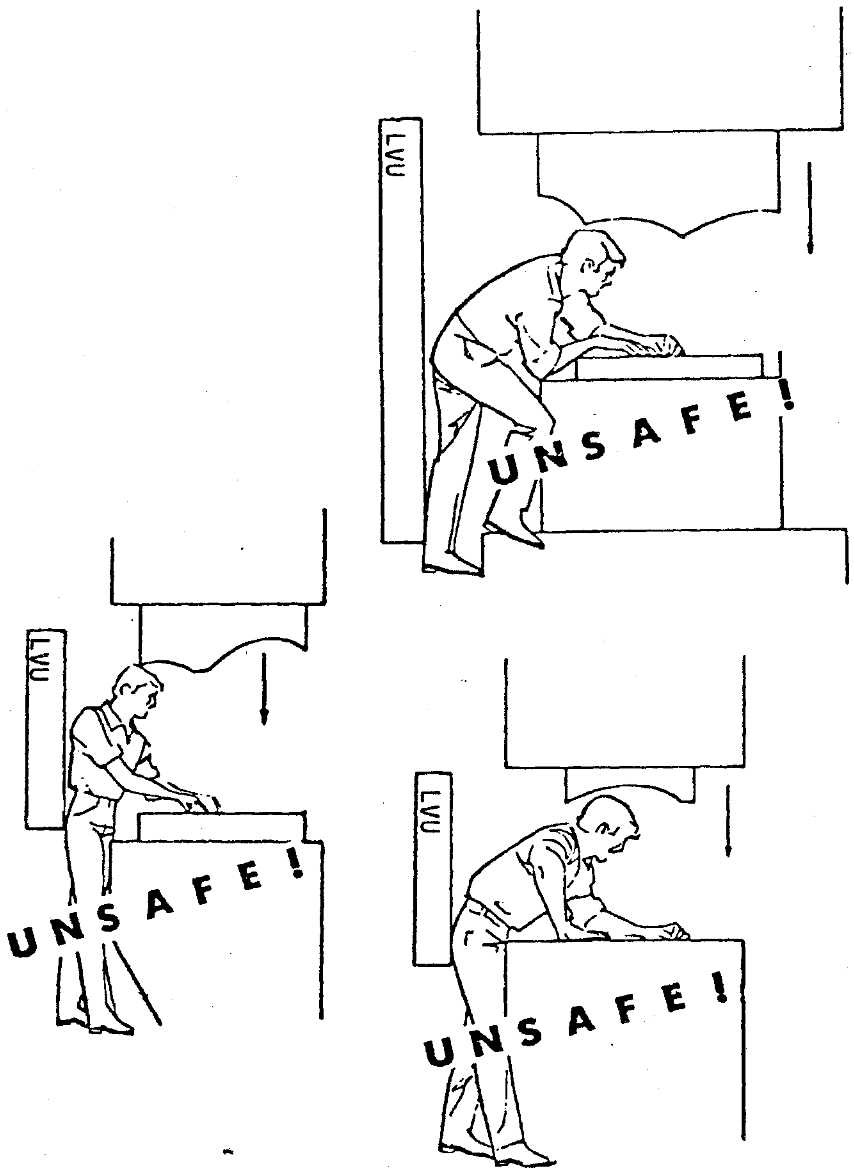

Fig. 3

Standing, Leaning, Climbing behind the safeguarded area. If it is possible to stand, lean, or climb behind the safeguarded area without breaking the light beam of the LVU, supplemental guarding must be provided to prevent this condition.

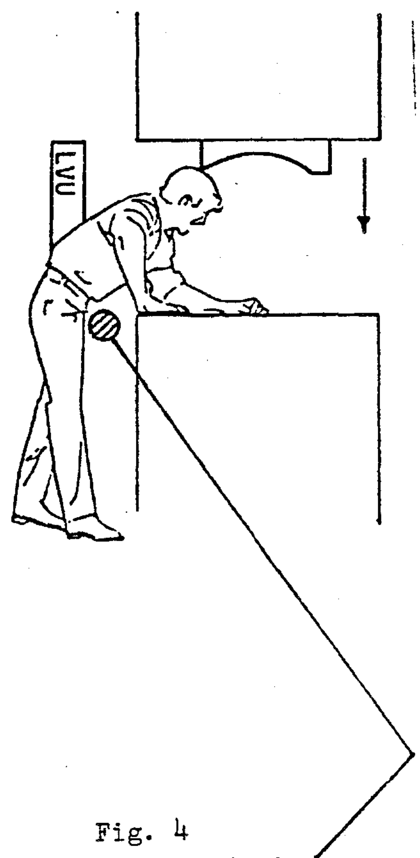

Fig. 4
Mechanical barrier to prevent standing behind the safeguarded area

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7. Author(s) M. Barash	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Purdue University School of Industrial Engineering West Lafayette, Indiana 47907	10. Project/Task/Work Unit No.
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15. Supplementary Notes

16. Abstract (Limit: 200 words)

Quality, safety, and reliability considerations of an electro optical sensing device (light curtain) for safe hand feeding of automatically activated mechanical power presses are discussed. Self tripping light curtains are designed to stop movement of the press slide when the operator's hand penetrates the curtain during loading, and to resume movement after withdrawal of the hand. Under specifications of OSHA regulation 1910.217, only light curtains without self tripping capability are permitted on mechanical power presses in the United States. A variance was granted to one company, based on better safety and higher performance of self tripping light curtains compared to two hand controls. Safety assessment of these devices can include safety of individual components and system integration of these components. Today's technology allows for construction of light curtains which would have a no accident probability of 99.9994 percent over 50 years for 100,000 presses. Safety of the light curtain component depends on design, construction, manufacturing quality, and conditions of use. It should be designed to minimize the possibility of its circumvention by machine operators. Other components discussed include two hand or palm buttons, clutch and brake, redundant or auxiliary brakes, solenoid air valve, brake monitors, additional guarding, and cam setting. Safety aspects of system integration include installation, inspection, and monitoring. Liability is also discussed.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

NIOSH-Publication, NIOSH-Contract, Contract-210-80-0034, Machine-tools, Machine-operators, Injuries, Electronic-devices, Machine-guarding, Safety-equipment, Industrial-safety

c. COSATI Field/Group

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