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A case study of the occupational stress implications of working with two different actuation/safety devices

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A case study was conducted using an automatic sphygmomanometer to compare the stress encountered by workers using two different machine actuation/safety devices. The experiment took place in a small metal stamping plant as part of a government authorised comparison of the devices. Six experienced female workers separately performed the same task on the same power presses using either a photo electronic or a two-hand button device. These two devices perform dual duty as both machine actuators and machine safeguards. Blood pressure at the ankle and heart rate were measured periodically and a questionnaire was administered.

The case study approach to this experiment was necessitated by government restrictions which limit the population of workers experienced with both devices. The results of the case study are twofold: (1) For the small population tested no significant difference was found in the stress measures examined for machine operators; and (2) A feasible in-plant methodology is demonstrated for unobtrusively monitoring worker populations exposed to machine related stress.

Keywords: Working stress, safety devices, machine tools

Introduction

Mechanical power presses are some of the major metal working machines used in industry. The contract stamping industry, which specialises in using mechanical power presses to make parts for automotive, appliance and similar manufacturers, has annual sales of approximately $27 billion (AMSA, 1980). Frequent and severe injuries to press operators are associated with the use of these machines. Mechanical power presses ranked first among metalworking machines in need of machine safety research by the National Institute for Occupational Safety and Health (NIOSH, 1975).

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These machines are fairly simple in their working principle a ram is driven on to a workpiece which is cut, formed, or bent by dies attached to the ram and the machine bed.

Hand feeding of parts is often the most economical way to run a press. Different parts are produced on the same press using different combinations of press actuators and safety devices. The variable tooling, variable safety devices, variable controls and low skill often lead to ineffective guarding, poor ergonomic design and consequent problems Presses can be actuated by either two-hand controls, foot pedals or automatic controls. They can be safeguarded using barriers, gates, two-hand controls, or other devices. Actuation mechanisms and safeguarding methods which will maximise operator performance are preferred by the management of press shops.

A small stamping plant near Cleveland, Ohio, received Government permission to set up an experiment to operate presses using Sick Optik Electronics presence sensing devices (non-contact sensors) to function both as safeguards and as actuators. This is called self-tripping. The main experiment

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was designed by the Occupational Safety and Health Administration and by the stamping company to provide comparative safety information on operating presses with either a presence sensing device as the actuator/safeguard or with a two-hand control as the actuator/safeguard (Federal Register, 1976).

A presence sensing device creates a 'sensing' plane in which an object (a hand) is automatically detected by optical and electronic means. Normally, the device is used to deliver a control command to the machine to stop if something interferes with the field. In the experiment, the control system of a press was designed to respond to the extraction of an object (a hand) from the sensing plane by initiating a press stroke. The device serves two functions: It stops the machine if the worker reaches in at a dangerous moment and it is the interface control by which the worker causes a machine stroke to take place. The two-hand control consists of two palm buttons located a safe distance from the press dies. The palm buttons also constitute a double duty device. They protect the worker by occupying the hands at a safe distance from the danger and they are the interface control by which a worker causes a machine stroke to take place.

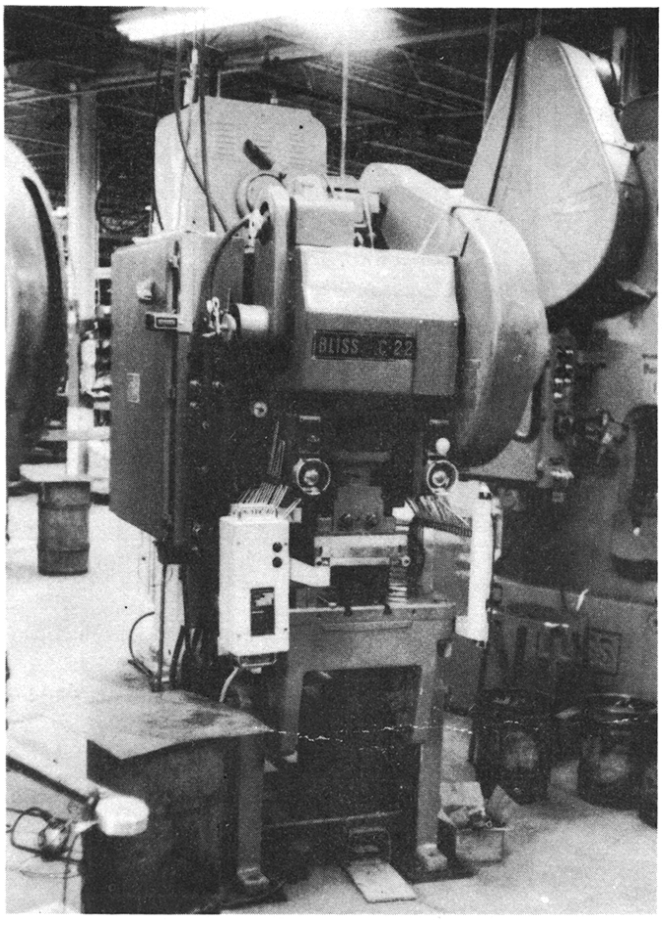

Fig. 1 The power press used in the study. Note that the same power press uses either actuator/safety device. The two push buttons are seen in the lower part of the Figure. The box mounted on the left is the self-tripping mechanism. It generates an intangible photo optical plane the height of the box.

The main experiment involved five presses operated by any workers who volunteered to participate. The company was required to make descriptive reports concerning:

- Injuries which might occur (none has occurred to date)
- Non-routine incidents when the curtains provided protection
- Brake maintenance
- Productivity
- Set-ups for which self-tripping was not feasible

The main experiment has been in progress for over five years. (Federal Register, 1978.)

The case study being reported here was conducted to examine a selected sub-sample from the ongoing main experiment. It was hypothesised that the stress of working with self-tripping systems would be less than the stress of working with two-hand controls, thereby contributing to the self-tripping system being a safer mode of actuation.

This case study addresses only the comparative stress aspects of working on self-tripping systems versus the two-hand control system (Salvendy and Sharit, 1982; Sharit and Salvendy, 1982). System reliability and productivity aspects of the two types of actuators have been reported elsewhere (Salvendy *et al*, 1981).

Method

Subjects

Six female operators, aged 21 to 59 years, employed as power press operators at the Interlake Stamping Corporation, participated in this study. Three younger (less than 40 years of age) and three older (more than 40 years of age) operators participated in the study in order to assess age effects of the variables studied. All subjects had at least six months of experience with each of the true actuator/safety devices of the two-hand control and self-tripping system. All subjects volunteered for the experiment.

Equipment and software

Three E.W. Bliss open back inclinable (OBI) power presses with a capacity of either 22 or 45 tons (220 or 448 N) were utilised (Fig. 1). All of the machines were equipped with both kinds of actuator/safety devices, namely the two-hand control device and the self-tripping presence sensing control. One of the power presses had a 14 in (356 mm) and the others had a 9 in (229 mm) light curtain which operated even when the two-hand control system was used for actuation.

The physiological measurement equipment was a Dynamap model 845 automatic sphygmomanometer which was integrated with a microprocessor repeatedly to measure and record systolic, diastolic, mean blood pressure and heart rate. To provide for short sampling intervals and to sample more than one subject, the Dinamap was modified. The microprocessor reset line was connected to a NOVA 3/12 computer and a manifold. Through software control, the Dinamap took measurements from up to six subjects sequentially (Knight, Salvendy and Geddes, 1979).

Inflation of blood pressure cuffs placed on the operator's ankle occurred via the microprocessor which was under the control of computer software. The cuff's deflation was, in turn, under microprocessor control which reduced the

Table 1: Descriptive statistics for physiological stress indicators for the two-hand control and self-tripping devices. The table presents the mean and standard deviation values for all the subjects during the entire two days of working in the self-tripping mode and two days in the two-hand control mode. (Without baseline adjustments.)

Variable measure	Self-tripping systems (STS) X	SD	Two-hand control (THC) X	SD	% difference of STS from THC
Mean Blood Pressure* (mm Hg)	135·56	4·97	133·50	4·66	+1·54
Systolic Blood Pressure* (mm Hg)	157·81	4·97	156·67	4·04	+0·73
Diastolic Blood Pressure* (mm Hg)	121·00	5·25	118·86	5·56	+1·80
Heart Rate (beats/min)	96·82	8·11	96·00	6·80	+1·85

*All blood pressure data were taken at the ankle. Blood pressure readings were taken at 5 mm Hg intervals.

pressure in the cuff in 5 mm Hg steps. Blood pressure measurements were transmitted through the same two cuff lines used for cuff inflation and were based on the pulse wave amplitude during obstructing steps. Heart rate was also determined. The measurement sequence starting with cuff inflation required a period of 20 to 35 s, depending on the degree of the suspected movement artifact which caused the Dinamap to pause. The software made provisions for temporary shut-offs (lunch and other breaks).

At times, due to machine breakdown or other emergency situations, the number of subjects on the power presses did not remain the same during the course of the experiment. The system was designed to handle such cases and a simple control action modified it to monitor the remaining working operators at the same specified intervals.

The computer software initiated measurements at approximately 8 to 10 min intervals. The sampling time variation was due to Dinamap's sensitivity to suspected movement artifacts and the degree of leg tension in the subject which delayed the readings. Zero measurements resulted if there was calculation uncertainty. At such occurrences, Dinamap was programmed to take a second reading from the same subject after an elapsed period of 60 s to avoid missing data.

Design of experiment

A total of six subjects participated in the study. The subjects were divided into two groups. Group 1 consisted of two old and one young subjects and they performed their

Table 2: Summary of ANOVA data for the physiological stress indicators during self-tripping and two-hand control actuation of power presses by six female industrial workers

		Blood Pressure (at ankle)							
		Mean		Systolic		Diastolic		Heart Rate	
Source	DF	F	P	F	P	F	P	F	P
Group	1	1·99	0·29	1·18	0·32	1·34	0·37	5·09	0·15
Age	1	0·00	0·98	0·04	0·86	0·33	0·62	0·04	0·86
Group x Age	1	0·33	0·63	1·51	0·34	0·52	0·55	0·04	0·87
Method	1	1·56	0·30	2·39	0·22	1·38	0·32	0·09	0·79
Method x Group	1	0·03	0·88	6·20	0·09	0·15	0·72	0·36	0·59
Method x Age	1	0·73	0·46	0·63	0·49	0·13	0·74	0·06	0·82
Period	3	1·65	0·25	1·32	0·33	3·30	0·07	3·83	0·05
Period x Group	3	0·05	0·98	0·06	0·98	0·09	0·96	1·05	0·42
Period x Age	3	2·35	0·14	1·06	0·42	3·02	0·09	3·14	0·08
Period x Method	3	0·62	0·61	2·16	0·10	0·55	0·65	0·30	0·83

Group = Day shift or night shift
Age = Young or old
Method = Self-trip or two-hand control
Period = Each subject's testing time was divided into 16 equal periods
DF = Degrees of freedom
"F" = From ANOVA table
P = Statistical significance of "F"

Table 3: Response to feeling tone checklist questionnaire. Each response category can have a maximum of 12 (6 subjects x 2 days)

Questions		Self-tripping Days 1 and 2			Two-hand control Days 1 and 2		
		Better than	Same as	Worse than	Better than	Same as	Worse than
1.	Very lively		6	6		5	7
2.	Extremely tired	10	2		8	4	
3.	Quite fresh		6	6		5	7
4.	Slightly pooped	4	7	1	3	9	
5.	Extremely peppy	2	4	6	2	3	6
6.	Somewhat fresh		9	3		9	3
7.	Petered out	10	2		7	5	
8.	Very refreshed		5	7		3	9
9.	Fairly well pooped	7	5		6	6	
10.	Ready to drop	11	1		11	1	
	Total	44	47	29	37	50	32

work during the day shift. Group 2 consisted of two young and one old subjects and they performed their work during the night shift. Because of this confounding effect of group with age the data pertaining to 'Group' must be interpreted with caution. Group 1 performed the first two days in self-tripping mode followed by two days in the two-hand control mode; whereas Group 2 performed in the reverse order.

Procedure

Each subject spent two working days (16 h) operating a press equipped with each of the two control modes (two-hand and self-tripping). The parts being stamped during the test were kept uniform during the test. Prior to and after the working day, one measure each of baseline and recovery blood pressure and baseline and recovery heart rate were obtained. During job performance subjects were sampled at 8-to-10 min intervals. Because of the cuff's placement around the ankle, there was no interference with the task. However, due to this placement location the recorded blood pressure readings were higher (by 22·4 mm Hg/ft (73·5 mm Hg/m)) than normally observed from arm cuff readings.

At the end of each day, Pearson's 'feeling tone checklist' (Pearson and Byars, 1956) questionnaire was answered by each subject regarding her physical and psychological attitude at that moment.

Results and discussion

The numerical results of this case study are presented in the interest of presenting a complete report. The caveat which must accompany them is that they are results on a selected sub-sample of a non-random worker population and are not generalisable to other worker populations. The population of workers from which a sample could be taken was biased by the nature of the main experiment. Also the total number of subjects available for study was quite small (12). The physiological values shown in Table 1 reveal that the four selected stress measures vary from 0·7 to 1·8% between the two actuation modes. These differences were neither statistically significant (Table 2) nor clinically meaningful which disproves the original hypothesis that using the selected measures the self-tripping actuator would be less stressful than using the two-hand actuator. These statistically non-significant values do not alter even when we double the degrees of freedom due to the high rejection risk (beta level) associated with the small subject population. The significant effect of selection on heart rate is expected. For the purposes of the ANOVA, the work day data was divided into four roughly equal periods. The lowest stress level, as measured by heart rate, was experienced at the first period and the highest stress experienced in the third period.

The Chi-square data for the feeling tone checklist (Table 3) revealed no statistically significant differences between the three possible responses of "better than", "same as", and "worse than"

$$(X^2_2 \text{ df} = 4{\cdot}64; p > {\cdot}10).$$

These results are surprising since one intuitively expects less stress for power press operations with the self-tripping system than with the two-hand control. The offsetting factor appears to be that during the above experimentation when the operators used the self-tripping systems they produced, on average, 30% more parts than with the two-hand control. This 30% improvement in productivity utilising the self-tripping system was achieved at the same stress level as that experienced by the workers utilising the two-hand controls. However, due to the very small number of participating workers in the sample studied and the relatively short duration of the study, experiments involving a much larger sample size are needed to establish definitely whether or not operator stress levels are different for the two systems.

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