LITERATURE REVIEW OF IMPACT NOISE REDUCTION IN THE SHEET METAL INDUSTRY

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Abstract: In the sheet metal industry, high levels of impact noise are associated with the frequent occurrence of noise induced hearing loss in workers. A literature review is presented of research on impact noise from punch and power presses in this industry. The review shows that considerable work has been done, and that much is understood about, the noise generation mechanisms in these machines. While more fundamental research will undoubtedly produce greater insight, there is a need for much more design and development work to produce quieter machines and processes for the sheet metal industry.

1 INTRODUCTION

Most recent data from the Australian Bureau of Statistics [1] suggests that 185,000 workers are employed in the metal products manufacturing industry in Australia. A large proportion of these people probably work in environments where high levels of noise are generated by impacts which occur during the processing of sheet metal products. Potentially damaging impact noises occur in many operations in the sheet metal industry such as shearing, punching, piercing and forming. Materials handling often produces significant impact noises as well, for example, when sheet metal products are stacked or moved on roller conveyors. In many instances noise enclosures do not provide a practical noise reduction strategy, and personal hearing protectors provide less than ideal protection for the workers. These factors give a strong motivation for developing sheet metal machinery in which impact noise is controlled and reduced at the source.

Since 1991, the Acoustics and Vibration Centre has had a major research program on the reduction of impact noise in the sheet metal industry. This research has been sponsored by Worksafe Australia, the Australian Research Council and BHP Building Products. This literature review, which has been prepared as a part of this program, and which concentrates on punch and power presses, shows that a considerable body of knowledge exists regarding the fundamental nature of impact noise. While the principles of impact noise generation in these machines are relatively well understood, much work remains to be done in designing and developing sheet metal machinery which is inherently less noisy.

2 IMPACT NOISE FROM PUNCH AND POWER PRESSES

Many researchers have studied impact noise from punch, power presses [2–49] and other impact noise sources [50–110], although relatively few significant articles on noise reduct ion from punch and power presses have been reported in the last ten years. In more recent times, world-wide research funding has been directed into noise reduction and modelling of complex structures such as automobiles and aeroplanes, and noise reduction using active noise control; rather than practical solutions to common manufacturing noise related problems for which there is little financial incentive. During the 70s and early 80s, when occupational health and safety first became topical, several studies on the reduction of press noise were conducted.

Sallee and Guy [37] in an early study on punch press noise control noted, contrary to popular belief, that the contact of the punch and the die was not always the most significant noise source. Frequently other components were responsible for equal or greater sound pressure levels, particularly with automated units. They were able to achieve a noise reduction of greater than 8 dB at the operator station by: isolating the die from the main press frame; adding a cover to close the space, in the main frame, under the die; substituting rubber washers on the stripper bumpers; and modifying the end ejector cam to reduce the sharpness of the kick.

In a review of noise and vibration control for impact machines, Bruce [53] concluded that: absorptive treatment of the factory surfaces can only achieve a maximum noise reduction in the order of 3 dB(A) at the operator station; partial enclosures of machines can yield as much as 10 dB(A) of noise reduction; total close-fitting enclosures can achieve up to 20 dB(A) noise reduction; well-designed large total enclosures can achieve as much as 30 dB(A) noise reduction, as they can be constructed of heavier materials with no openings for stock, product or scrap; and operating the punch in shear can reduce the noise levels by about 15 dB(A). These claims appear to be well above other published data and the authors' personal experience.

Studies by Shinaishin [41, 42] on punch press diagnostics, noise control and impact-induced industrial noise note that it is necessary to have a thorough knowledge of the noise generating mechanisms in the press. He used a combination of waveform analysis, frequency analysis, time-frequency analysis and cross-correlation analysis; with the objective of identifying the causes of sound generation and selecting the components to be treated. The analysis included extensive simultaneous measurements of sound levels, acceleration and positions of moving parts. He advised that in all cases the sound spectra were broad and exhibited little or no sharp peaks, indicating that the excited structures were vibrating in many modes. He also advised that a 70% increase in machine speed raised the overall noise level by 5–10 dB(A), and that hard steel feedstock generated about 5 dB(A) more noise than mild steel feedstock. In experiments with high speed stamping presses, Shinaishin achieved noise reductions of 12 dB(A) by reducing the maximum blanking force through shearing the die. He noted that the application of this method should be used with care, since it may affect the product quality.

Shinaishin [41] also tabled the following explanation for the mechanism of press noise generation. During the cutting operation a large force is developed and stress builds up in the feedstock material, with an equal force in the opposite direction building up in the press frame. Upon fracture of the feedstock the two opposing forces set both the feedstock material and the press frame into transient motion. He emphasised that the noise thus produced could be lowered by reducing the vibration amplitude, it's frequency, or reducing the radiation.

This explanation of strain energy generated noise by Shinaishin was recently discussed by Williamson [48]. Williamson developed the concept of this noise as *spring-back noise* from the machine components. Williamson noted in a report on the reduction of impact noise in the sheet metal industry that in the cutting process strain energy builds up in the press components as the forces increase leading up to the cut. This strain energy is suddenly released when the cut or *break-through* occurs. The physical effect of the fracture is to force the press components with a negative step function of amplitude to virtually equal the maximum force. Impulsive motion of the press components following this sudden release was defined as spring-back, hence spring-back noise was the noise generated by such a motion.

Allen and Ison [2] identified and outlined the principal noise sources on a number of punch presses of varying capacity. They noted that although the relative importance of each source varied from press to press, and job to job, they were able to rank them as follows: impacts associated with the die; turbulence noise due to air ejection; metal-to-metal impacts of feed and ejection components; stop start impact of automatic feed mechanism; vibration from the flywheel and sheet metal fastened to the press; clutch and brake mechanism; and vibration of the press surface. On a 50 ton press Allen and Ison achieved a noise reduction of 13 dB(A) by enclosing the die area. This was achieved by making a cardboard mock-up enclosure and then using this prototype to design an operational enclosure from metal and plexiglass.

In an investigation to locate the major noise radiating areas on a 4 ton punch press, Koss and Alfredson [25] located the sources of transient sound through the use of multiple-input correlation theory. The inputs were acceleration, measured at the die, the support plate and the crankshaft collar; while the output was the sound pressure level measured at the operator station. They showed how sound was radiated due to changes in the force-time curve.

Koss [26] also used a conventional vibrational shaker to simulate the frequency response of the above punch press. A comparison was made between the experimental results obtained from the shaker analysis and the blanking operations for mild and stainless steel.

An experimental evaluation of several commercially available mufflers to reduce air exhaust noise from clutch and brake activation was conducted by Daggerhart and Berger [14]. They advised that the peak sound pressure level of pneumatic exhausts could be reduced by as much as 34 dB(A) by the installation of an appropriate air exhaust muffler.

Petrie [33] concentrated his efforts on obtaining an optimum tool alignment and made simple press tool modifications in order to reduce the noise due to the blanking operation of a 15 ton C-frame punch press. Several operational parameters were considered, such as: clearance between the punch and the die; the location of the workpiece on the travel of the punch with its resultant impact velocity; the angle of the shear on the punch and die; and shear area. Petrie noted that the minimum punch impact velocity compatible with sufficient punch travel through feedstock resulted in a reduction of up to 8 dB(A).

Stewart *et al.* [44] in a comprehensive report on the noise parameters influencing a 60 ton power press studied the effects of the feedstock shear strength, hole punch diameter, feedstock thickness, punch impact velocity and the punch and the die clearance, on the peak sound pressure level. They observed a reduction of 15 dB(A) as the percentage clearance between the punch and the die was reduced from 20% to 6%. *Percentage clearance* was defined as the difference in punch and die diameters, multiplied by 100 and divided by the feedstock thickness. They also noted that for percentage clearances less than 6% the noise level was relatively constant for a given thickness, while at percentage clearances above 8% the noise level increased proportionally with increasing punch to die clearance.

Strasser [46] believed that a selective combination of several simple measures, based chiefly on common sense and sound engineering knowledge, would yield highly satisfactory noise reduction results. He noted that the noise produced by a press increased as the load approached the nominal capacity of the press. Therefore, to reduce the noise level, it is important to select a press with ample capacity, approximately 50% to 100% above that required.

Cook [12] discussed his experience in reducing noise on a wide range of power presses using various types of barriers with different materials, mufflers, vibration isolators and absorptive silencers. He advised that the most common design problem associated with applying noise control principles to power presses was the need to make allowance for frequent access to the machine. Cook also stated that it is possible to reduce the overall noise in a crowded press shop from 7–10 dB(A) by the use of absorption treatment. The authors believe these figures to be unlikely in practice due to vast area of panels that would be required and the associated high cost of implementation. The previously considered figure by

Bruce [53] of 3 dB(A) is more plausible.

A mathematical 2-dimensional model of a punch press frame vibrations and acoustic power output was formulated by Brickle [6]. This model was used to determine the relationship between structural dimensions and generated noise levels. He stated that in most cases analysed, the third vibrational mode was predominant and that it was sufficient to take only the first three modes into account in the calculation of the acoustic power, the fourth mode contributing very little.

In a study of three punch presses with different capacities, Koss [27] compared the sound radiation for the same loading. He standardised the characteristic shape of the fall-off regions for the force-time curves. This was achieved using plexiglass as the feedstock, since it was brittle and produced fracture at the maximum load, resulting in fall-off of load similar to a step decrease in the force. The force history was also statistically repeatable. A least squares fit of the peak sound pressure level associated with each transient sound to the peak force was found to be of the form: $L_{peak} = a + b\log_{10} P_{peak}$ where; L_{peak} was the peak sound pressure level (dB(A)), and P_{peak} was the peak force (kN).

Chee [7] also conducted a research survey of punch press noise. He concluded that there was insufficient data available either to construct a general model which would predict press noise from a wide range of machinery, or to assist with a reliable noise reduction program. He later published [8] a comprehensive review of punch press noise characteristics. In summary these were: the sound pressure level was proportional to shear area of the feedstock; and the sound pressure level dropped as the cutting-blade shear angle was increased until it reached a minimum at 12°, thereafter no benefit was measured. For practical angles of shear, in the region of 2–4°, a noise reduction of about 8 dB(A) was noted; the punch to die clearance was more critical with thicker feedstock; the punch to die clearance was related to the feedstock material properties and the type of fracture taking place; and the sound pressure level increased with punch impact velocity until a maximum sound pressure level was reached.

Koss and Moffatt [29] studied the structural response of a 170 kN C-frame punch press. They studied the first mode shape and concluded that it was responsible for a significant portion of the sound radiation. They also concluded that it was very difficult to dampen the press frame due to its large mass and stiffness. Koss [31] later reported overall noise reductions of 1–2 dB(A) using a tuned mass absorber and constrained layer damping treatments applied to the press frame. He achieved this by attaching sets of tuned absorbers to the press bed. A constant mass of 40 kg and varying thicknesses of neoprene rubber were combined to create spring mass systems.

In a follow up study Koss and Moffatt [30] reported mode shape, radiation ratio (σ_{rad}) and damping as a function of frequency for the same press. They concluded that a value of unity could be assumed for σ_{rad}, for machine structures with frequencies above 1000 Hz. For frequencies below this, σ_{rad} could have almost any value and the value was dependent upon how well the structural mode shape was matched with the wavelength of sound in air at the modal frequency and upon air transmission paths through the machine. They also reported that the damping ratio values were operation dependent.

Jeyapalan and Doak [74] showed that σ_{rad} can be used for accurately predicting the noise radiated by a decaying oscillator if the mean square velocity of the oscillator and σ_{rad} are known in the frequency band of interest. This result is specifically of interest for expanded-metal press noise predictions as the press frame vibrations decay rapidly between cuts.

In a report on machinery noise Jeyapalan and Halliwell [75] used acoustic modelling to predict the equivalent sound pressure level at the operator station. This method provided a quick and easy method of accurately predicting overall root-mean-square sound levels given a force input to the machine and the subsequent vibrational response. The method is applicable to any machine which can be identified as a combination of separate sound sources.

Coleman [9] investigated the sound radiated by a hand-operated punch by combining experimental measurements with sound radiation and classical vibration theories. The predicted sound pressure levels from acceleration data and σ_{rad} were within 5dB of the experimental results.

Finite-element modelling of punch presses and forge hammers was performed by Al-Sabeeh [111]. Sound radiation at modal resonance from a punch press frame was predicted using classical structure-borne radiation considerations. He noted that the press structure was responsible for a large portion of the overall noise radiation. He concluded that a much better structure-borne noise prediction could be made if σ_{rad} of steel plates were known. He suggested that an experimental study on steel plates of various thicknesses and boundary conditions be undertaken to yield a set of empirical relationships that approximated σ_{rad}.

Coleman and Hodgson [10] demonstrated the benefits of acoustic intensity contours by mapping the sound field around a 350 kN punch press. All three events of the punch press cycle were analysed individually by partial-coherent residual spectra-analysis techniques to help rank the noise sources per event. Also, the transient response of a single-degree-of-freedom system, subject to the actual punch press forcing function, demonstrated the response to be stiffness controlled rather than mass controlled.

Coleman [11] later studied the sound radiation from repetitive transient vibrations using multi-channel digital signal processing with an emphasis on transient impact machinery. He showed that the partial-coherent residual spectra-analysis technique failed to accurately identify and rank acoustic sources on complex machinery, characterised by omni-directional energy flow and/or high spatial coherence throughout the structure. He concluded that ringing noise was not generated solely by resonant frequencies, therefore techniques that affect the entire frequency range were preferable for reducing noise. He demonstrated that increasing the stiffness of the punch press reduced both the resonant and non-resonant sound radiation. Coleman also successfully employed the use of cepstral analysis to separate overlapping pressure waveforms. This allowed him to separate events within transient machine cycles and reverberant conditions.

Significant pioneering research by Richards *et al.* has led to a better understanding of impact noise mechanisms. Richards *et al.* [35, 85–94] published a comprehensive series of papers based on extensive experimental and theoretical studies conducted at the Institute of Sound and Vibration Research, University of Southampton. Since their publication these papers have served as the definitive reference on impact noise throughout the world.

Like Shinaishin, Richards and Stimpson [35] advised that the force within the punch press body builds up and the whole machine is strained until the feedstock material fractures. At this stage the strain energy in the press body and the feedstock material must be redistributed. This redistribution leads to vibration of the whole press body and subsequent noise radiation. The paper also describes work carried out on passive and active cancellation systems used to arrest the spring-back of the press body following feedstock fracture and explains the limitations of such systems. Richards and Stimpson stated that well designed shear and/or cutting with low percentage clearance was superior to active cancellation. They also used the Energy Accountancy Equation to relate the noise radiated directly to the squares of the large rates of change of force against time; where $f(t)$ was defined as the force pulse shape. This illustrated clearly the way that noise control, with the use of passive or active methods in designing the punch tooling, can be related directly to the one parameter $10 \log \sum [f(t)]^2_{\max}$.

Most recently Lam and Hodgson [77] used a numerical technique to predict the ringing noise from a $\frac{1}{3}$ scale model drop hammer, in a rectangular room. The technique was based on the Helmholtz integral equation with a modified Green's function to account for the effects of the enclosure. The vibration data required by the noise prediction technique was obtained by finite element predictions and impact response measurements. It was found that the noise prediction showed good general agreement with measurements, but at certain frequencies noise other than the ringing noise was found to contribute significantly towards the measured noise levels.

3 CONCLUSIONS

It can be seen from the above discussion that there is no single method of reducing noise from punch and power presses. A common conclusion to most articles is that there are generally several noise sources, each requiring separate and individual treatment. The following is a summary of the noise sources, reduction methods and techniques tabled by the various authors that are relevant to the present study:

1. The noise level is directly related to the impact intensity, that is, the sound pressure level is greater with higher forces acting over shorter periods of time; the time element is a very important factor;
2. Strain energy spring-back of the press components is a major noise generating mechanism;
3. Lowering the machine operating speed can reduce the overall sound pressure level by as much as 10 dB(A);
4. The cutting-blade characteristics are important and the following points should be considered when designing for minimum noise emission: provide rake to the edge of the cutting-blade so that the cutting is performed progressively in a smooth shearing action; stagger the cut by performing the cutting operation progressively instead of in one hit; extend the duration of the cutting action; employ the smallest blade clearance consistent with product quality; use clean and sharp cutting edges as higher forces are required to cut with dull cutting edges; and employ anything that makes the cutting action easier, such as lubrication. For punch and die sets a percentage clearance $\leq 6\%$ appeared to be optimal;
5. Absorptive treatment to factory surfaces will only yield a noise reduction in the order of 3 dB(A) at the operator station;
6. Effective inlet and exit treatment to a press enclosure is very important and usually difficult to achieve;
7. Partial enclosure of the press, such as enclosing individual noise sources, is not effective;
8. Increase the mechanical impedance of all moving parts by increasing the mass, stiffness, or damping;
9. Increase the stiffness without changing the mass is more effective than increasing both the stiffness and the mass together;
10. Radiation from impact tends to be broad-band noise, so techniques that reduce noise over the entire spectrum are preferable. Stiffness controlled noise reduction techniques reduce both resonant and non-resonant sound and vibration.
11. Where possible, decouple the energy source from the radiating source;
12. A press capacity of at least 50% and up to 100% above that required is suggested; and
13. The most common design problem associated with applying noise control principles to presses is to under estimate the necessity for frequent access to the various components of the press.

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