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EFFECT OF TOOLING PARAMETERS ON THE RELATIONSHIP BETWEEN THE RADIATED NOISE AND INDUCED FORCE IN SHEAR CUTTING OF SHEET METALS

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ABSTRACT

It has been shown theoretically by Evensen [1] that the noise radiated from impact forming operations is related to the time derivative of the force induced in the machine. In this paper, the validity of this theory is explored for a high speed sheet metal shearing process. Noise measurements were made for various shear blade tooling parameters, such as blade profile, blade clearance and speed of cutting, while dynamic cutting forces were measured simultaneously using a pressure transducer. Experiments include the cutting of profiled sheet metal products as well as flat sheets. The profiled specimens used for this investigation were roll formed sheet steel products with an approximately sinusoidal profile produced by BHP Building Products, Australia. For this product, eight different shear blade profiles of varying blade angles and rake were designed and produced. Comparison of experimental results with theory is discussed along with practical applications to the design of high speed sheet metal shearing operations with reduced radiated noise.

INTRODUCTION

Little published work is available on how blade parameters affect radiated noise for sheet metal shearing operations. The effect of blade parameters on the radiated noise and the induced force-time history in punching or piercing machines has been considered by Sahlin [2], Koss [3,4] and Shinaishin [5] and then in more details by Burrows [6] and Evensen [1].

Burrows and Evensen showed both theoretically and experimentally that there exists a relationship between the radiated noise level and the time derivative of the force induced inside a punching machine. The purpose of this paper is to examine the validity of this relationship for a shearing operation. By knowing the influence of the tooling parameters on the relationship between the radiated noise and the induced force, it will be possible to reduce the noise generated by careful control of tooling parameters.

The effects of tooling parameters on noise radiated from the shearing of flat metal sheets [7] and profiled sheets [8] were investigated previously. In the current investigation, it is the nature of the relationship between tooling parameters, the induced force-time history and the radiated noise level which is considered.

THEORETICAL ANALYSIS

The theoretical relationship between the radiated noise level $L_{eq}(A)$ of a punch press and the induced force-time history was first given by Evensen [1] and then developed by Richards [9].

$$L_{eq}(A) = 10\log\sum\left[f'(t)\right]^2_{max} + C = L_{f'} + C \tag{1}$$

where $f'(t)$ is the time derivative of the force f(t) in the punching and piercing operation and C is a constant.

There are two main assumptions in the derivation of Equation(1): (a) the structure is linear and is only excited at the point of cutting with no backlash noises; and (b) the radiated noise arises only from structural vibration.

In examining this formulation for punching noise, using different materials and thicknesses, Burrows [6] found that the slope of the line of best fit to his data was not unity as implied in equation (1). Hence, based on Burrows results, equation (1) may be modified as

$$L_{eq}(A) = mL_{f'} + C \tag{2}$$

where m (the slope of the line of best fit) and C for Burrows data are given in Table 1. It can be seen from Table 1 that for steel , m and C are essentially independent of the material thickness, with m being approximately 1 and C being approximately 49. However, for aluminium, m and C appear to be a function of thickness and are quite different from the values for steel. It is not clear from the literature whether the value of m may be influence by factors other than the type of material. Burrows results in Table 1 were only obtained from experiments using a constant speed but different clearances. Thus in the experiments described here, not only the clearances are varied but also the speed of cutting and the profiles of the sheet. Also the current experiments relate to sheet metal shearing rather than punching or piercing.

Table 1

Material	Thickness (mm)	m	C
Aluminium alloy	1.58	0.67	61.9
	3.22	0.81	58.3
	6.28	0.95	52.9
Hot rolled steel	2.09	1.09	47.2
	3.01	1.07	48.1
	6.20	1.08	48.7
Bright drawn steel	3.19	1.03	49.2
	6.32	1.05	49.6

EXPERIMENTAL PROCEDURE

For this set of experiments, a hydraulically operated experimental shear provided by BHP Building Products, Australia was used, see Figure 1. Two types of blade assemblies were designed and manufactured: straight and profiled. For cutting flat sheets with different thicknesses, a straight blade assembly was made with the capacity to change its shearing angle and its clearance between the blades, Figure 2. The specimens used for cutting were flat cold rolled steel metal sheet with a width of 50.0 mm and four different thicknesses: 1.0, 1.5, 2.0 and 3.0 mm.

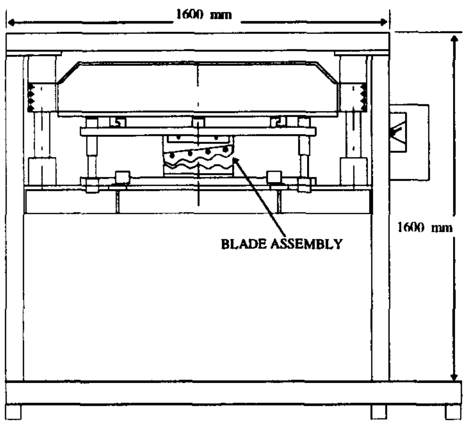

Figure 1 Experimental shear

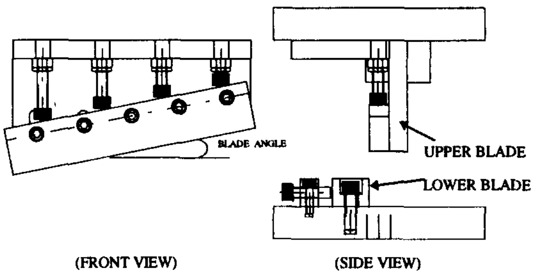

Figure 2 A straight blade set

The profiled metal sheets which were used for these experiments were roll formed cold rolled sheet steel products with an approximately sinusoidal profile produced by BHP Building Products, Australia, Figure 3. The specimens used were zinc/aluminium alloy coated steel with a width of 300 mm and a thickness of 0.45 mm.

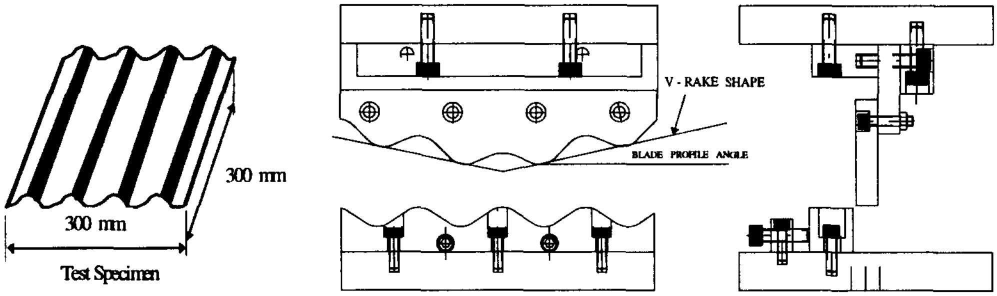

Figure 3 Profiled sheet specimen and a profiled blade set.

For cutting these profiled sheets, eight different blade sets were designed and manufactured, see Figure 3. For each of these blade sets, the lower blade has the same profile as the specimen but the upper blade profile has been designed with a constant shearing angle, resulting in a progressive shear across the feedstock. Five of the eight blade profile angles used were 0°, 0.5°, 1°, 2° and 4°. To illustrate the function of these blades, Figure 4 shows four stages of the cutting process using a blade with a straight rake and a 2° blade angle. Three more 2°, blades but not with a straight rake, were made and used in these investigations. The rakes of these blades were ∨, ∧, and ∨∨ with respect to the lower blade. Figure 3 shows a blade with a ∨ rake shape.

During the cutting process, the pressure in the hydraulic cylinder that operates the shear was measured with a pressure transducer. An example of the variation of this pressure with time and its derivative is shown in Figure 5. L_f in equation (2) can be estimated from the squares of the peaks of the pressure derivatives given in Figure 5.

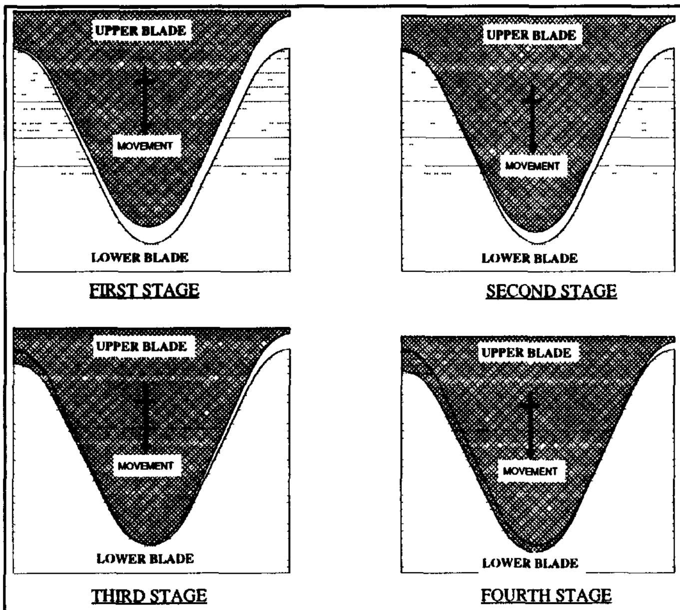

Figure 4 Four stages of cutting with a set of 2° shear angle sinusoidal blades.

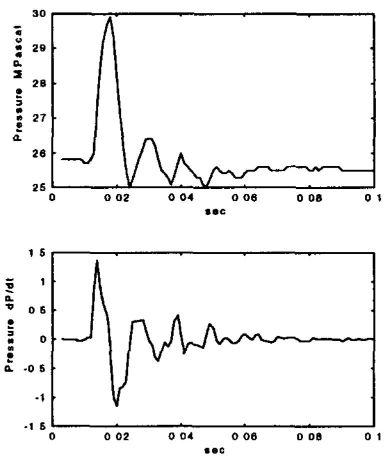

Figure 5 Typical measured pressure and its derivative

INSTRUMENTATION AND MEASUREMENTS

The noise level $L_{eq}(A)$ was measured by using a Bruel & Kjaer (B&K) type 2231 Sound Level Meter (SLM) which was equipped with a $\frac{1}{2}''$ B&K condenser microphone type 4155. The blade displacement was measured by using a linear variable differential transformer (LVDT). The cutting force was measured dynamically by measuring the hydraulic pressure in one of the two cylinders using a high sensitivity piezoelectric charge mode pressure sensor, PCB type 112A. The signal from the pressure transducer was conditioned using a charge amplifier, B&K type 2635. All these data were recorded simultaneously and digitally using a Boston Technology PC30 A/D data acquisition card controlled by a Toshiba T3200SXC laptop computer. These data were then analysed to establish a relationship between $L_{eq}(A)$ and $L_{f'}$.

RESULTS AND DISCUSSION

Two sets of experiments were conducted for a straight blade and one set of experiments was conducted with profiled blades.

STRAIGHT BLADE:

Two experiments were conducted using a straight blade:

1) with a constant speed of cutting, 40.2 mm/s, and the clearance between the blades varied from 0.05 mm to 0.46 mm; and
2) with a fixed clearance of 0.05 mm between the blades and the speed of cutting varied from 26 mm/s to 257 mm/s.

1)- Constant speed:

The variation of $L_{eq}(A)$ with $L_{f'}$ for a constant speed of 40.2 mm/s and 40 combinations of clearances and sheet thicknesses is given in Figure 6. By using linear regression analysis, a line of best fit to the data has been obtained as

$$L_{eq}(A) = 0.91 L_{f'} + 87.15 \qquad (4)$$

with a correlation coefficient of 81%. It can be seen that while there is some data scatter in Figure 6, the data for various sheet thickness appear to follow the linear relationship quite well. It must be pointed out that the estimate of the pressure derivative from the pressure signal is highly sensitive to any noise present in the signal. Thus the data scatter in Figure 6 is not considered excessive. The value of m is close to unity as implied in equation 1 and compares reasonably well with Burrows's results for steel using a constant speed and different clearances as given in Table 1.

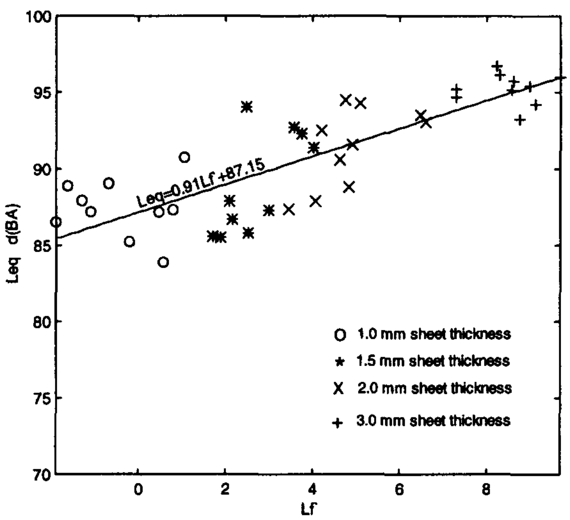

Figure 6 Variation of $L_{eq}(A)$ with $L_{f'}$ for constant speed of cutting and various clearances between the blades.

2)- Fixed clearance:

The variation of $L_{eq}(A)$ with $L_{f'}$ for a fixed clearance of 0.05 mm and 56 combinations of cutting speed and sheet thicknesses is given in Figure 7. By using linear regression analysis, a line of best fit to the data has been obtained as

$$L_{eq}(A) = 0.55 L_{f'} + 90.67 \qquad (3)$$

with a correlation coefficient of 85%. As has already been observed for the experiment conducted with a constant speed of cutting, the data for various sheet thicknesses follow the linear relationship quite well but with a different slope $m = 0.55$.

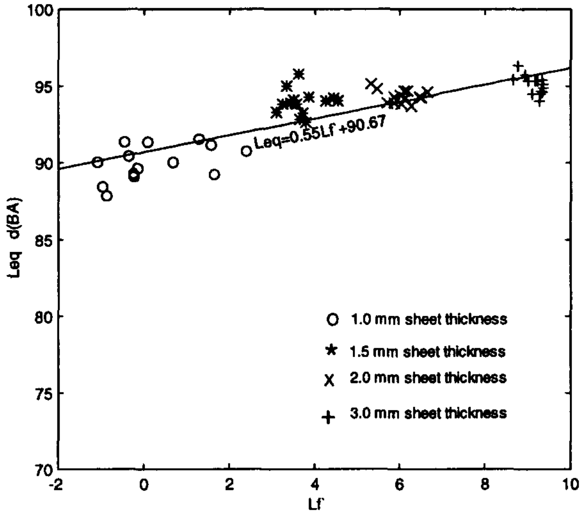

Figure 7 Variation of $L_{eq}(A)$ with $L_{f'}$ for a fixed clearance between the blades and various speeds of cutting.

PROFILED BLADES:

Experiments for the profiled sheets at constant thickness, 0.45mm, were carried out with 8 different blade sets at a constant speed of cutting, 68.3 mm/s. The variation of $L_{eq}(A)$ with $L_{f'}$ for a fixed clearance of 0.10 mm and a constant speed of 68.3 mm/s with 21 combinations of profile angles and rakes is given in Figure 8. By using linear regression analysis, a line of best fit to the data is given by

$$L_{eq}(A) = 1.85 L_{f'} + 88.93 \tag{5}$$

with a correlation coefficient of 83%. The data for various profiles and rakes follows a linear relationship reasonably well but with a slope $m = 1.85$, quite different from that for a flat sheet. This result suggests that m is dependent on the profile of the sheet.

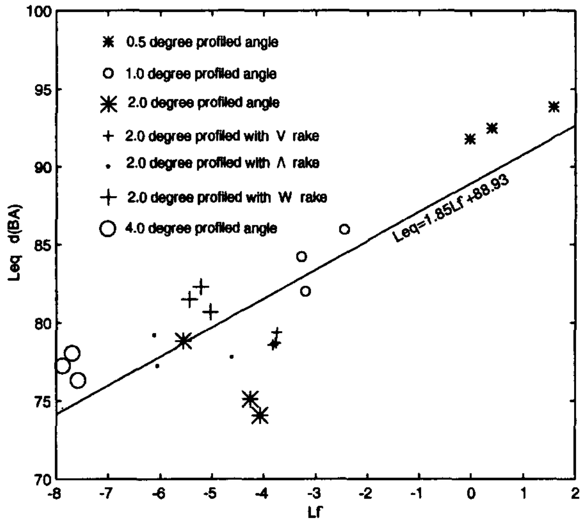

Figure 8 Variation of $L_{eq}(A)$ with $L_{f'}$ for a constant speed of cutting but different blade profiles

It can be seen from equations (3), (4) and (5) that when compared with m, C appears to be relatively independent of the tooling parameters (clearance, speed of cutting and profile) for a given machine.

CONCLUSIONS

The effect of various tooling parameters on the relationship between the radiated noise level $L_{eq}(A)$ and the induced force-time history $L_{f'}$ has been examined experimentally. Results show that $L_{eq}(A)$ is linearly related to $L_{f'}$. For cutting flat steel sheets at a constant speed, the shape of the line of best fit to the data is very close to 1, which agrees with the theoretical prediction and Burrows's experimental results for punch presses. However, m was found to be significantly different from 1 when the speed of cutting was varied and when profiled sheets were cut.

These experiments demonstrate that the induced force-time history can be manipulated by changing the tooling parameters (such as blade angle, clearance and speed of cutting) to reduce the radiated noise.

ACKNOWLEDGMENTS

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