THE PREDICTION OF NOISE SOURCES IN FORGING MACHINES

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INTRODUCTION

It has been established [1] that noise is generated in impact forming machines by four main mechanisms. These are:

(a) The radial billet expansion at the instant of impact which contributes significantly towards the peak sound pressure but is generally of very short deviation (about 1ms) [2].

(b) The sudden deceleration of the tup (platen) on impact. This can produce very large peak pressures (~150dB) [3] of duration about twice the impact time. This source makes only a small contribution to Leq.

(c) Vibration of the machine structure in its normal modes i.e. "ringing". This lasts typically for 500ms and gives by far the dominant contribution to Leq [4,5] .

(d) The rapid ejection of air from between the approaching die surfaces prior to impact. Calculations of this effect [6] indicate that it can make an important contribution to the peak sound pressure but not to Leq.

The first three mechanisms belong to the domain of linear acoustics i.e. sources in which the sound waves consist of small pressure perturbations produced by the small movement of boundary surfaces and for which the non-linear equations of fluid mechanics can be approximated by the linear wave equation

$$\nabla^2 p = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \qquad (1)$$

subject to the boundary condition

$$\frac{\partial p}{\partial n} = -\rho\frac{\partial u}{\partial t} \qquad (2)$$

to be satisfied on the radiating surface.

However, source (d) is essentially an aerodynamic source produced by very large pressure and velocity perturbations between colliding die surfaces and for which the full non-linear equations of fluid mechanics must be used.

The following sections will describe the mathematical techniques which have been used by the Birmingham research team to predict the above-mentioned noise sources.

NOTATION

c	Speed of sound in air
G($\underline{r}$,$\underline{ro}$)	Free field Green's function
i,j,k	Integers labelling finite-difference grid in direction of increasing r,z,t respectively
Leq	Equivalent continuous noise level

Notation Continued.....

$\underline{n}$	Outward normal vector
N	Number of surface elements
N_I	Number of interior points
P	Acoustic pressure
P_{ij}^{k}	Finite-difference solution of wave equation
P ($\underline{r}$)	Spatial part of sound pressure field
$\underline{r}$	Position vector of field (measurement) point
$\underline{ro}$	Position vector of source point on S
S	Arbitrary vibrating surface
t	Time
u_ω	Harmonically varying surface velocity
β	Ratio of time step to distance step in finite-difference scheme
γ	Ratio of principal specific heats of air
ρ	Density of air
ω	Angular frequency

MATHEMATICAL TECHNIQUES

Analytical

It is sometimes possible, for simple geometry, to obtain analytical solution to equation (1) by the Standard Method of Separation of Variables as in the case of billet expansion. Even here the final step of Fourier synthesis has to be carried out numerically because of the time dependence involved.

Finite-Differences

In principal it is possible to solve any problem in linear acoustics by a finite-difference solution of equation (1). In the general case of 3 space plus 1 time dimension, where it is necessary to cover a large volume of space-time with a grid of points the demands on computer storage can be prohibitive. However, this method becomes feasible, when the physical situation can reasonably be approximated by an axi-symetric problem, such as the case of tup deceleration.

The application of finite-differences is facilitated further if boundary surfaces are perpendicular to co-ordinate directions. However, tups of varying shape, where this simplification did not hold, have been treated [7] .

Helmholtz Integral Equation

It is possible to reformulate equation (1) as an integral equation which in the case of harmonic time dependence is given by

$$p_\omega(\underline{r}) = \frac{1}{4\pi} \iint_S \left[p_\omega(\underline{r}_0) \frac{\partial G}{\partial n}(\underline{r},\underline{r}_0) - i\rho\omega u_\omega(\underline{r}_0)\, G(\underline{r},\underline{r}_0) \right] dS \qquad (3)$$

The main advantages of this formulation are:

(i) The boundary conditions on the radiating surface and at infinity are automatically included in equation (3).

(ii) The number of dimensions is reduced from three to two as only a surface integral is involved.

(iii) A numerical method can be developed for dealing with arbitrary shapes by dividing the radiating surface into a number of elements.

Method of Characteristics

The basic non-linear flow equations are the conservation of mass, conservation of momentum and the equation of state for air. By taking suitable linear combinations of these equations, it is possible to write them in characteristic form [6]

$$\frac{du}{dt} \pm \frac{2}{\gamma-1}\frac{dc}{dt} \pm c\left[\frac{u}{r} + \frac{1}{h}\frac{\partial h}{\partial t}\right] = 0 \quad (4)$$

along the characteristic lines in r-t space given by

$$\frac{dr}{dt} = u \pm c \quad (5)$$

where u and c are the local fluid speed and sound speed respectively and h is the instantaneous distance between the colliding dies.

Using a method similar to that employed in the finite-difference technique, it is possible to step forwards in time calculating new values of u and c in terms of earlier values.

NOISE SOURCES IN IMPACT FORMING MACHINES

As an illustration of the previous techniques, the method used for structural ringing will be described. The Helmholtz Integral technique described earlier has been used to predict the noise from the three principal modes of a high speed forming machine [5]. The vibrational response of the machine to an impulsive blow was calculated using a finite-element program. The surface element model of the machine is shown in Fig. 1. Fig. 2 shows a typical mode of vibration at 593 Hz together with the predicted sound pressure level distribution along the z-axis. The two plots correspond to free-field conditions (continuous line) and the case having ground reflections (dotted line). Fig.2(c) shows the total sound pressure due to the summation of all three major modes and its comparison with experiment (square points); agreement is seen to be good.

CONCLUSION

A wide variety of mathematical techniques has been presented summarising the theoretical work done on fundamental mechanisms of noise generation in impact forming machines at Birmingham University, though several techniques can in principle be used for each noise source, one technique usually proves to be the most suitable.

These techniques have been implemented as a comprehensive program package for the prediction of impact noise.

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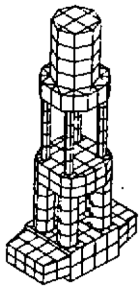

FIG. 1. Surface element model of forging machine

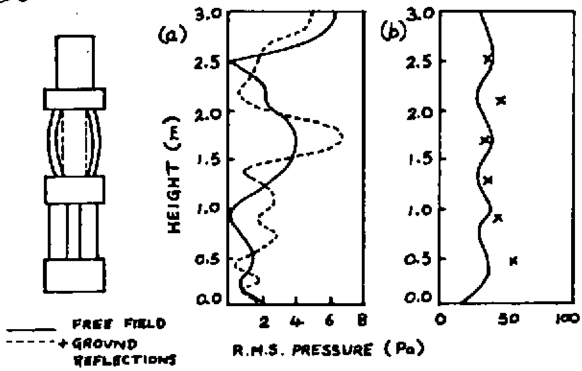

FIG. 2. Typical mode of vibration at 593 Hz.