Proceedings of The Institute of Acoustics

THE EFFECT OF GEOMETRY ON ACOUSTIC EMISSION

R Hill and S M A El-Dardiry

School of Physics, Robert Gordon's Institute of Technology, St Andrew Street, Aberdeen.

INTRODUCTION

It is already well established that acoustic emission can be used in a triangulation system for location of sources and some considerable success had already been achieved relating acoustic emission to fracture mechanics parameters. However, these developments have gone on with apparently little attention being paid to problems of the propagation and effective detection of acoustic emission. This situation has continued because of the relatively crude (though useful) measurement parameters in use such as count or count rate and other similar parameters which amount to little more than an emission/no emission parameter.

It has been apparent for some time now (1) that if acoustic emission is to develop then these gaps in our knowledge need to be filled.

A particularly important problem is that of effective source identification and if this goal is to be achieved a far more sophisticated system of data processing must be adopted and the acoustic behaviour of the propagation system and transducer must be known in detail.

If these problems are successfully overcome, the potential for acoustic emission is unlimited. Operational plant, particularly high investment plant can be operated throughout to full working life with the assurance that impending failure will be preceded by acoustic emission and safe shut-down. One use which particularly interests us is the use of acoustic emission as a method for maintaining the integrity of oil structures. If the relationship between acoustic emission and impending failure can definitely be established then costly and time consuming precautionary diving operations can be avoided and action need only be taken when it is known that action is needed.

SYSTEM RESPONSE

It is now apparent that burst type emission signals produced by resonant transducers are due to short acoustic emission stress wave transients striking the transducer. It is expected (2) that transients at source will be of short duration, probably monopolar, having spectral frequencies extending up into the low MHz frequencies and possibly as far as 10's of MHz.

In practice this source spectrum is likely to be modified by a series of factors which will cause the source event to be modified before it reaches the transducer.

These processes of modification can be listed as

1. Intrinsic attenuation
2. Frequency dispersion/mode conversion
3. Specimen resonance
4. Transducer/coupling layer resonance.

EXPERIMENTAL STUDY OF SOME GEOMETRY EFFECTS

Some of the main factors affecting the detected signal are outlined above. It remains to be seen how important they prove to be in the refinement of the acoustic emission technique.

Computer simulation of acoustic emission waveforms

Computer simulation of acoustic emission waveforms was carried out to investigate the characteristics of likely waveforms in more detail.

The stress waveform is assumed to be an ideal rectangular stress wave propagating with unmodified wave shape. The detecting transducer is assumed to act as a narrow band filter with a rectangular band pass window (4). The equation for the transducer response function is

$$V_n(t) = K\sigma_n T_n \frac{\sin\pi f_o T_n}{\pi f_o T_n} \nabla f \frac{\sin\pi\nabla f(t-t_2)}{\pi\nabla f(t-t_2)} \times \cos 2\pi f_o(t-t_2) \quad -(1)$$

where σ_n is the stress amplitude, T_n is the stress pulse width, f_o is the transducer resonant frequency, ∇f is the transducer bandpass and $V_n(t)$ is the transducer voltage. The function is restricted by the conditions $V_n(t) = 0$ for $t < t_2 - t_R$ and $t_2 = t_r + t_R$.

t_r = acoustic transit time $\quad$ t_R is transducer response time.

The simulation was found to work well when compared to face to face transmission waveforms at 200 kHz if a transducer bandwidth, ∇f, of 48 kHz was used (fig. 1).

In cylindrical structures, the radial divergence of the wave means that pulses arrive at the transducer with delay times controlled by the helical paths around the pipe. The introduction of helical paths produces a series of closely spaced waveforms $V_n(t)$ whose spacing is determined by the acoustic time delays operating (figs. 2 and 3).

Fast fourier transforms were performed on these pulses to identify the spectral characteristics of these signals. For pulses having any propagation distance in a pipe, and behaving in this ideal way, all the frequency information is contained within a bandwidth of about 50 kHz centred on the transducer signal. For a single pulse $V_n(t)$ most of the spectrum appears in the modulation side bands (fig. 4), but as the number of pulse reflections increases for increasing distances from the source, the amount of spectrum between the side bands increases progressively and the complexity of the spectrum increases (figs. 5 and 6). This type of information is very significant when considering how spectra are to be interpreted. If a perfectly flat broadband detector could be used from D.C. to say 25 MHz then signal fidelity would be maintained. However, operational requirements for reducing background noise, and the effect of attenuation at high frequencies restrict the useful frequency bandwidth to 50 kHz to 5 MHz or less.

Problems of signal to noise ratio mean that transducers with strong resonances are needed. Great care must be taken not to misinterpret modulation information due to pulse multiplication as being frequencies intrinsic to the acoustic emission mechanism.

Obviously frequency analysis of acoustic emission signals has great promise, but the technique must be used with care if it is to prove useful in a practical situation. Certainly any fine structure within the bandwidth of the transducer resonances must be expected to be due to modulation effects so that the Q factor and bandwidth of resonances must be known with some degree of certainty. It is not enough to know the transducer resonant frequencies alone.

Coupling layer between transducer and specimen

It is well known that the transmission coefficient for a thin layer separating two other semi-infinite media is controlled by the values of specific acoustic impedance and for the three media (3) the sound power transmission coefficient is given by the relationship

$$\alpha_t = \frac{4\rho_3 C_3 \rho_1 C_1}{(\rho_3 C_3 + \rho_1 C_1)^2 \cos^2 k_2 \ell + (\rho_2 C_2 + \rho_3 C_3 \rho_1 C_1/\rho_2 C_2)^2 \sin^2 k_2 \ell} \qquad -(2)$$

where α_t is the power transmission coefficient and $\rho_1 C_1$, $\rho_2 C_2$ and $\rho_3 C_3$ are the specific acoustic impedances of the three media and ℓ is the coupling layer thickness.

Since the transmission coefficient is dependent on the thickness of the coupling layer then it would be expected to have some effect on measured acoustic emission parameters. Figure 7 shows the variation of transmission coefficient with frequency for a variety of coupling thicknesses. The theoretical calculation assumes transmission from steel via a thin layer of grease into the PZT 5A of the transducer. Thick coupling layers show a marked variation of transmission coefficient with frequency while thinner layers less so. Assuming relatively thin layers (fig. 8) the transmission coefficient can vary between 0.5 and 1.0 below 500 kHz. Above this frequency the variation might be more marked.

While in the past some attempt has been made to control coupling thickness, these results suggest the need for much tighter controls. Without this tight control, measured difference in burst amplitude, count, RMS level, etc. between specimens might not be due to different acoustic emission characteristics for a material, but due to poor control of experimental conditions.

Effects of Specimen Geometry on Frequency Spectrum

It has been suggested by some workers that specimen geometry has little effect on acoustic emission parameters. This may be true for relatively small specimens using insensitive parameters, but experimental measurements and the simulation studies reported earlier suggest that extended structures will have a pronounced effect on the burst waveform. Preliminary studies by us suggest that frequency analysis is able to detect changes in specimen geometry. Figures 9 and 11 show transducer waveforms for simulation pulses propagating in specimens of differing geometry. While the pulse waveforms appear to be incoherent, differences in the burst spectra are seen (figs. 10 and 12).

RELATIONSHIP BETWEEN BURST AMPLITUDE AND COUNT RATE

Relationships between burst amplitude and count rate have previously been reported (4) as

$$V_{max} \quad \alpha \quad COUNT^{2} \qquad -(3)$$

where V_{max} is the transducer burst amplitude and COUNT is the count per pulse. An alternative relationship (5) is

$$V_{max} \quad \alpha \quad e^{K(COUNT)} \qquad -(4)$$

Experiments suggest that equation (3) fits the data shown in figure 13.

CONCLUSIONS

Computer simulation of acoustic emission waveforms suggests the sin x/x response of a transducer simulates the pulse waveform reasonably well. Frequency spectra of these pulses have fine structure near to the transducer resonances which is related to the modulation of the pulse waveform rather than its intrinsic frequency spectrum.

If valid comparisons are to be made between acoustic emission tests on various materials then the transducer coupling thickness must be highly reproducible.

Experiments suggest that the square of the count per pulse is proportional to the peak to peak burst amplitude.

REFERENCES

(1) HILL R; STEPHENS R W B. "Acoustic emission - evaluation of transducers and measurement systems". Ultrasonic International Proceedings 1973, I.P.C. Press 1974.

(2) CURTIS G. "Acoustic emission - 4. Spectral analysis of acoustic emission". Non-destructive testing, April 1974, pp 82-91.

(3) KINSLER L E; FREY A R. "Fundamentals of Acoustics". Second edition 1962.

(4) HILL R; STEPHENS R W B. "Simple Theory of Acoustic Emission - a Consideration of Measurement Parameters". Acustica, Vol. 31, No. 4, 1974, pp 224-230.

(5) BRINDLEY B J; HOLT J; PALMER I G. "The Use of Ring Down Counting". Acoustic Emission monograph. I.P.C. Press, 1974.

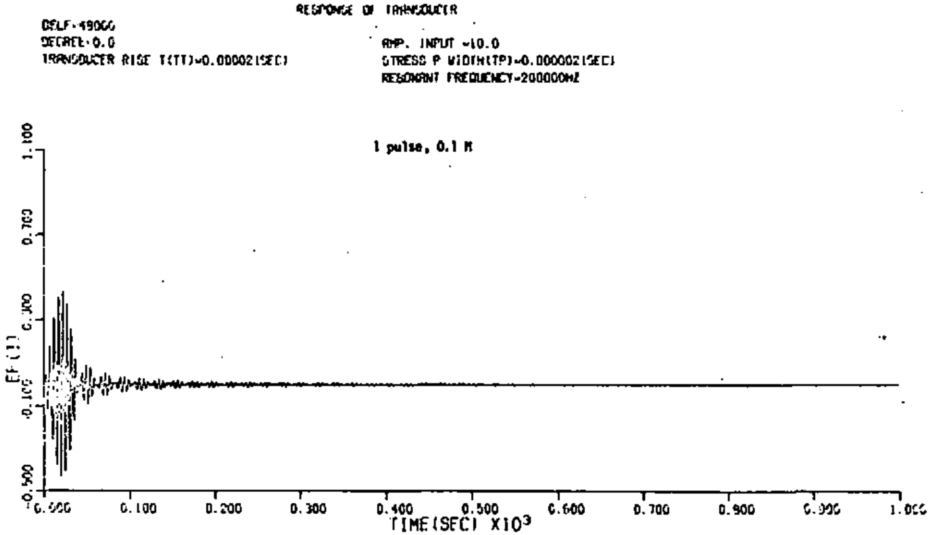

Fig. 1 : Computer simulated pulse used to synthesise transducer waveforms.

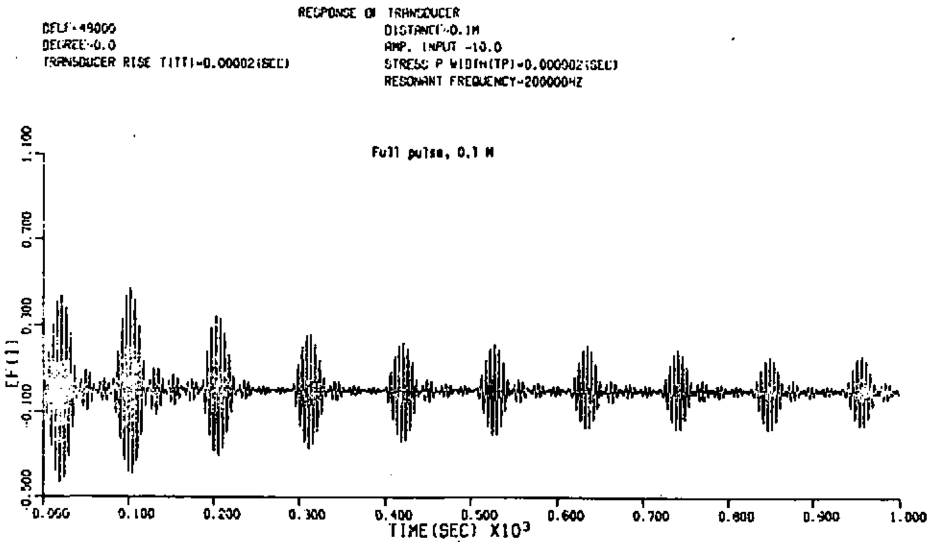

Fig. 2 : Computer simulated pulse in pipe for propagation distance of 0.1m.

THE EFFECT OF GEOMETRY ON ACOUSTIC EMISSION

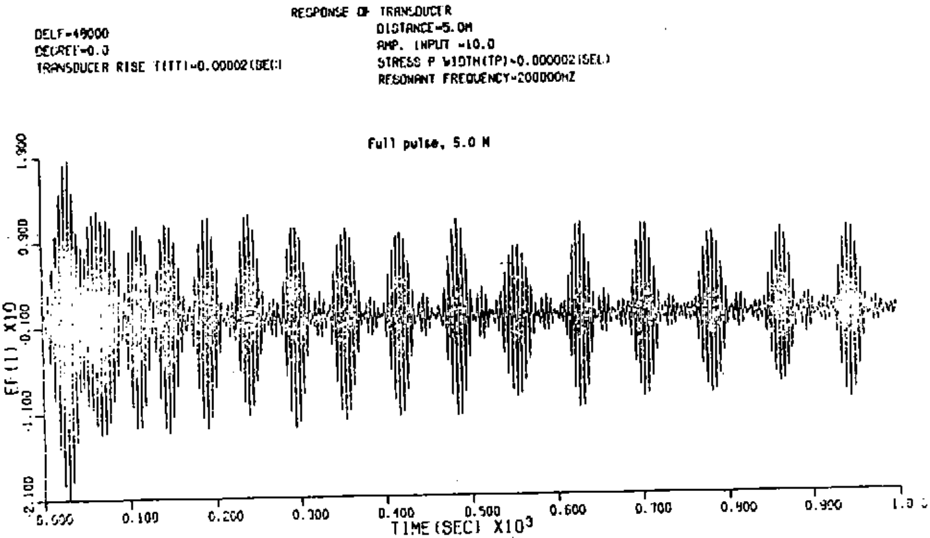

Fig. 3 : Computer simulated pulse in pipe for propagation distance of 5m.

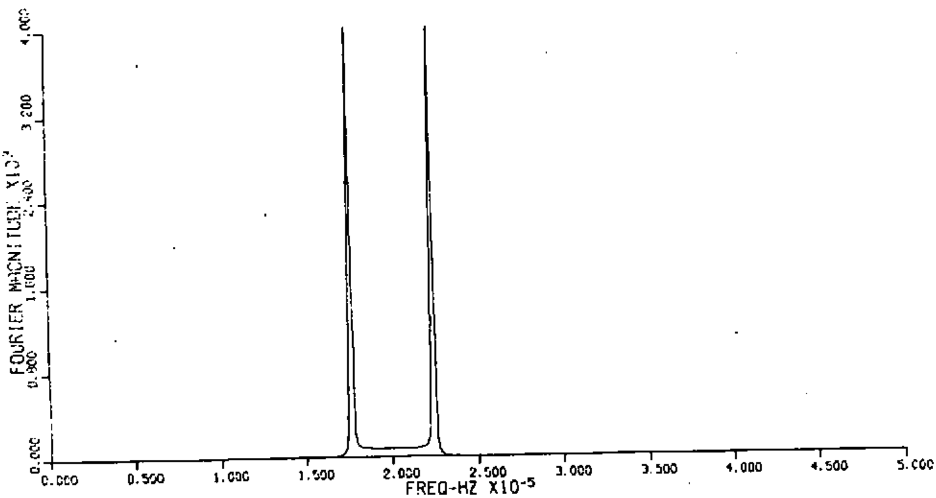

Fig. 4 : Frequency spectrum of calculated pulse in figure 1.

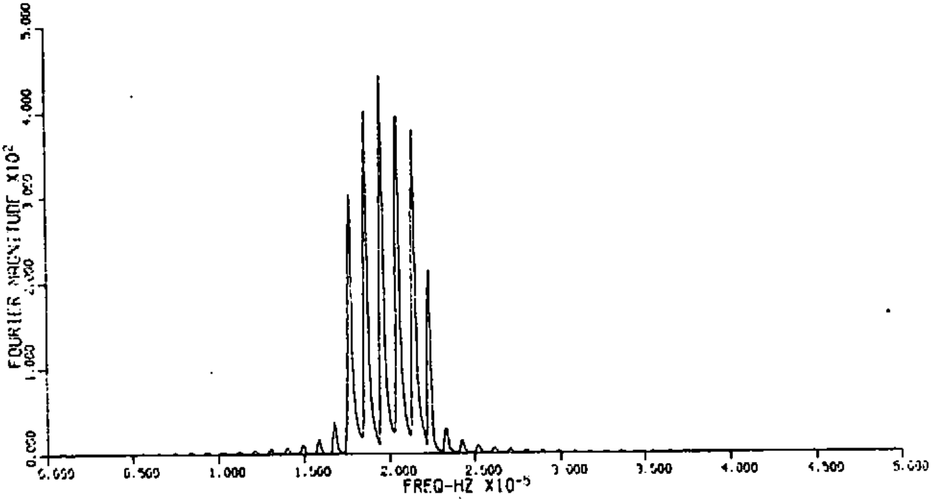

Fig. 5 : Frequency spectrum of calculated pulse in figure 2.

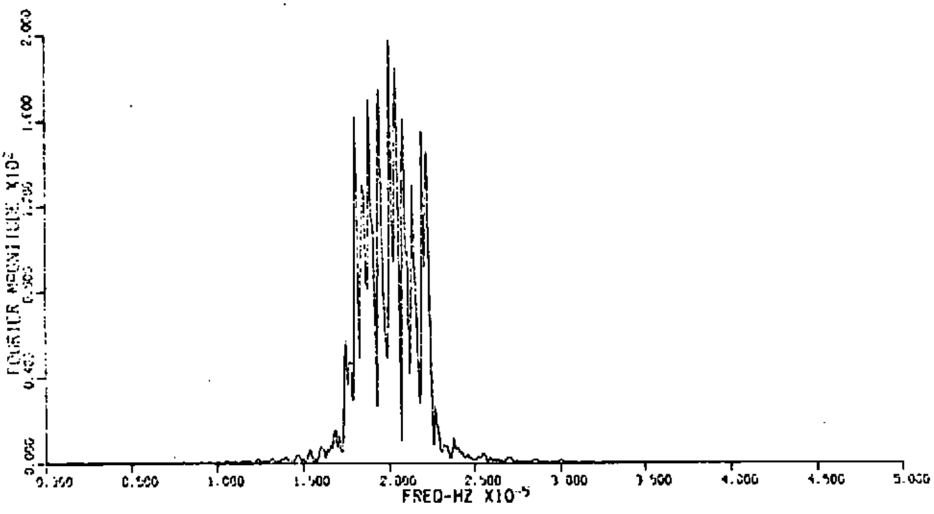

Fig. 6 : Frequency spectrum of calculated pulse in figure 3.

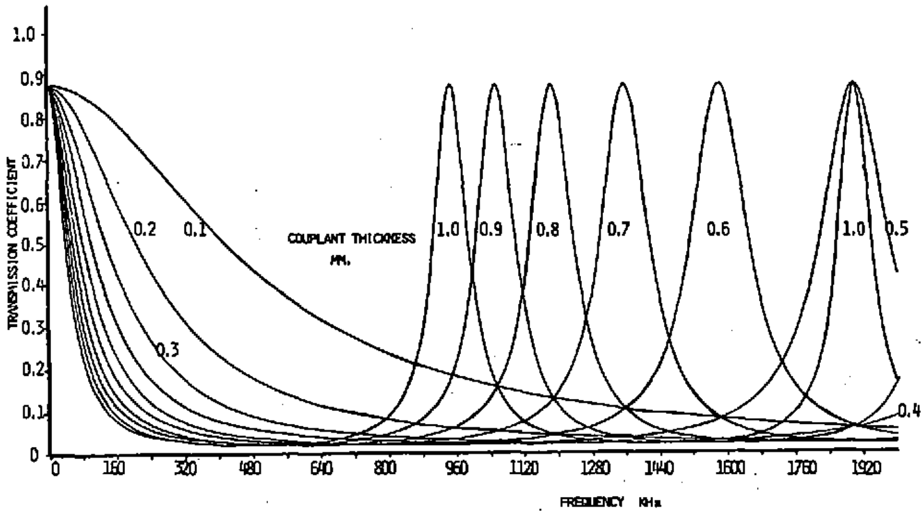

Fig. 7 : Variation of transmission coefficient with frequency for coupling thicknesses of 0.1 to 1.0 mm.

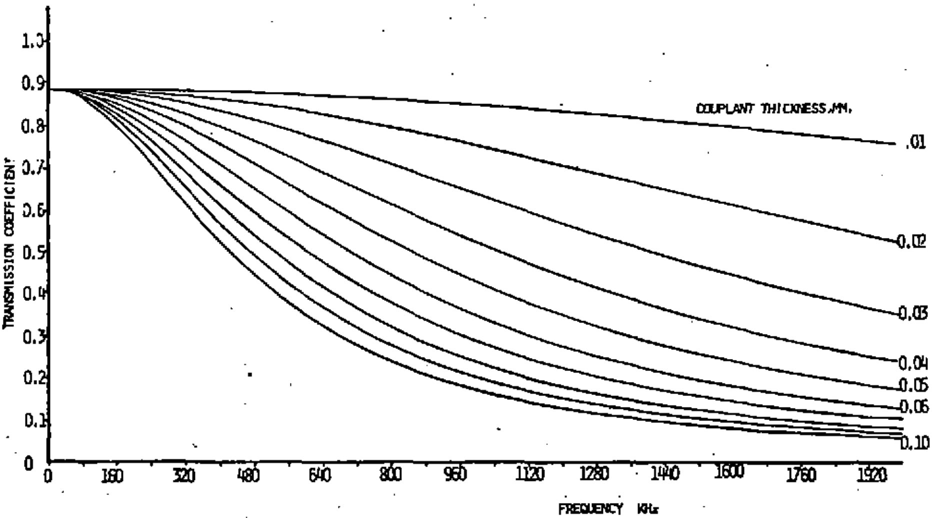

Fig. 8 : Variation of transmission coefficient with frequency for coupling thicknesses of 0.01 to 0.1 mm.

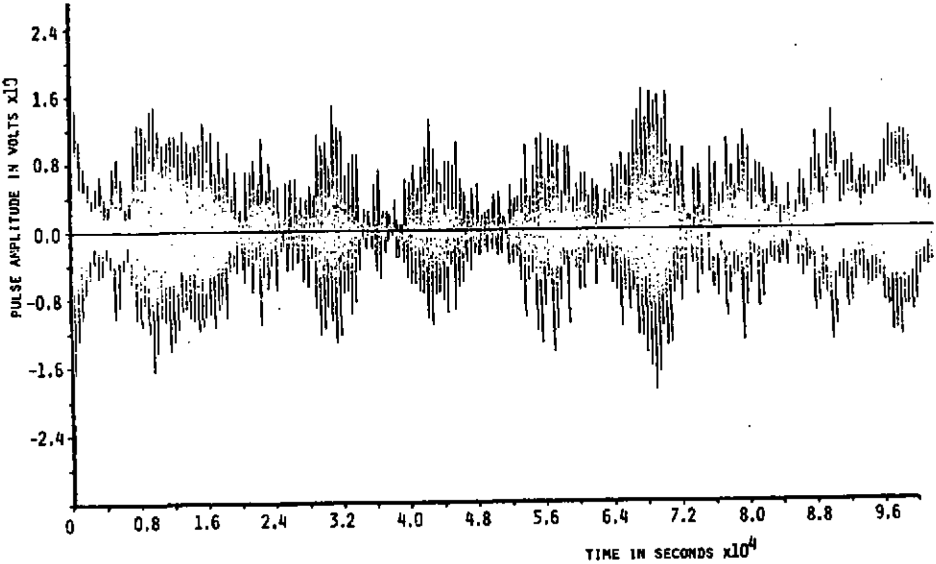

Fig. 9 : Simulated acoustic emission signal in bar (3x3x33.2 cm) with transducers 25 cm appart.

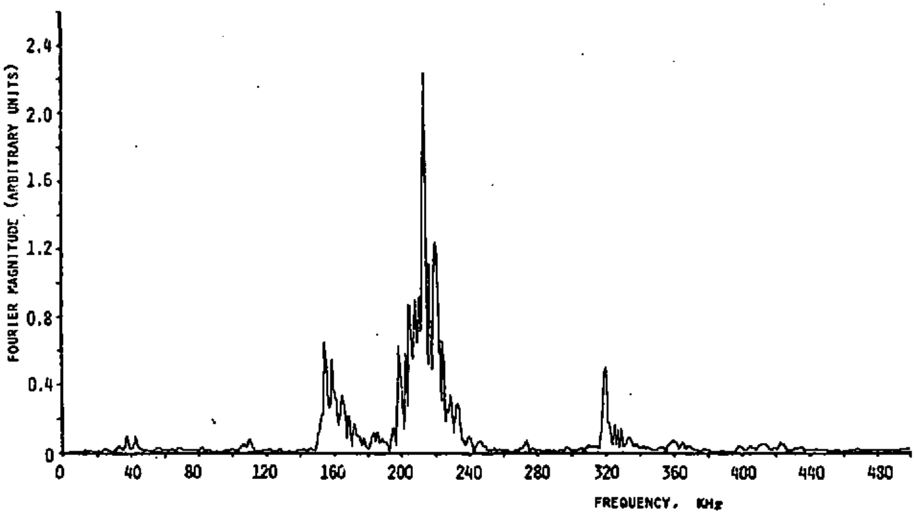

Fig. 10: Frequency spectrum of waveform in figure 9..

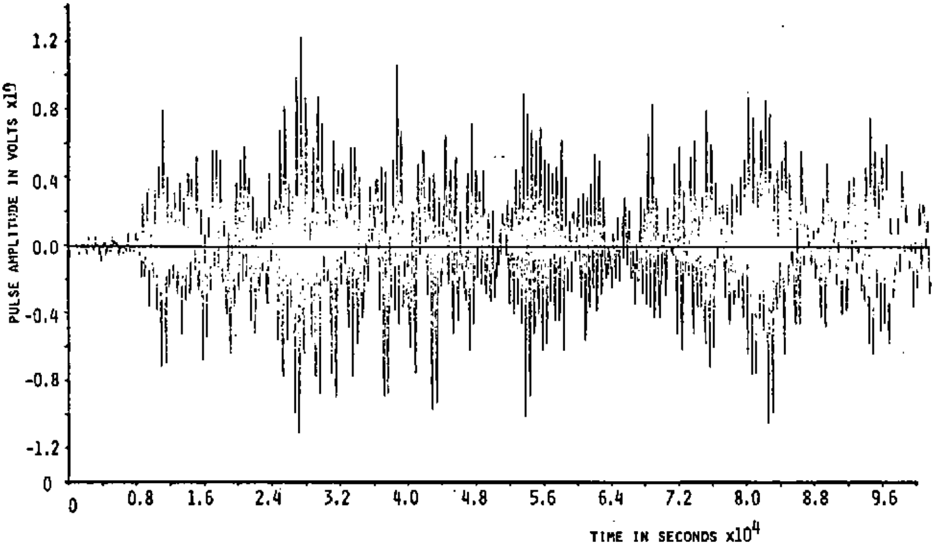

Fig. 11: Simulated acoustic emission signal in bar (0.6x5x69 cm) with transducers 25 cm appart.

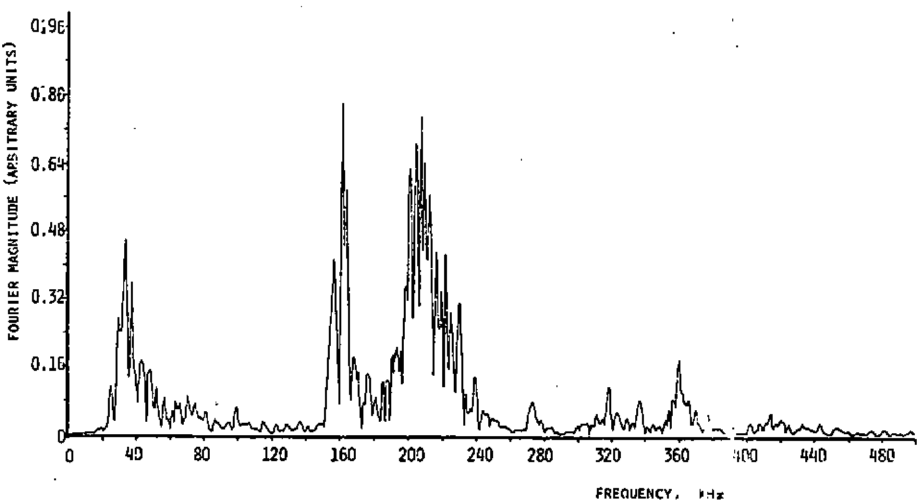

Fig. 12: Frequency spectrum of waveform in figure 11.

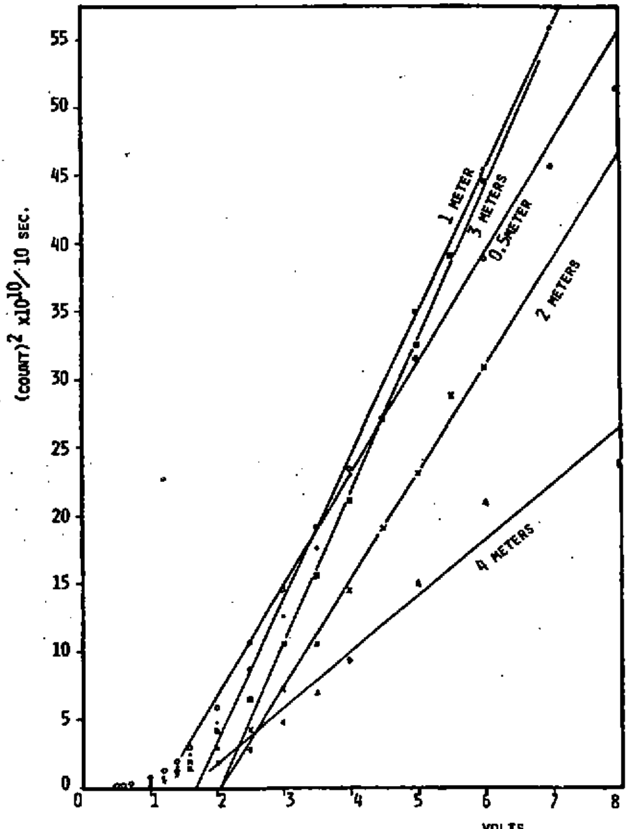

Fig. 13: VARIATION OF $(COUNT)^2$ WITH SQUARE WAVE INPUT TO SENDER FOR DIFFERENT PROPAGATION PATH LENGTHS.