THE EFFECT OF STYLUS SIZE ON THE PERFORMANCE OF A CHEMICAL RECORDER

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ABSTRACT. — The paper deals with the chemical recorder as used in most types of navigational echo-sounders and other underwater echo-ranging instruments. It is shown that when the time occupied by the stylus in traversing its own length (effective stylus time) is greater than the pulse duration, the performance, compared with a display without this limitation, is degraded. The effect may be represented as that of a low-pass filter in the output, the bandwidth of which is inversely proportional to the effective stylus time.

CONTENTS

LIST OF SYMBOLS

τ = Pulse duration.

v = Velocity of stylus.

b = Length of stylus in the direction of its motion.

T = Effective time-length of stylus $= \dfrac{b}{v}$.

F(t) = Time response of stylus due to unit impulse.

G(f) = Frequency response of stylus.

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1. — INTRODUCTION

1.1 *Description of Chemical Recorder.*

The chemical recorder is an intensity-modulated display which utilises a chemically impregnated paper on which a mark appears when an electric current is passed through it. Various electrolytes can be used to impregnate the paper but the one most commonly used in this country is a potassium-iodide solution containing starch — the starch being necessary to make the iodine visible when it is released by the passage of current. The current is fed to the paper via a stylus which acts as the anode; the negative electrode is a metal backing plate, known as the platen, on which the paper rests.

An application of this display, for which it most suited, is to underwater acoustic echo-sounding, or echo-ranging equipment, where it is required to display echoes returning from the sea bed or underwater objects, e.g. fish (1) or submarines. In such equipments it is necessary to measure the time delay between the transmission of a pulse of acoustic energy into the water and the echo returning from any object of interest, this time delay being a measure of the distance of the object from the transmitter. In synchronism with the transmission of the pulse of energy into the water a stylus is drawn across the paper and is fed with a current proportional to the returning echoes from the sea. The chemically impregnated paper is drawn, from a roll, across the platen at right-angles to the direction of motion of the stylus and hence each trace is written adjacent to, or slightly overlapping, the previous one, the extent of overlap depending on the speed of the paper across the platen.

An echo at a constant range marks at the same distance from the edge of the paper each time the stylus sweeps across and hence appears as a line parallel to the edge; similarly, an echo whose range is varying slowly appears as a line inclined at a small angle to the edge. The background marking on the paper, made up of reverberation and/or sea noise, tends to be random and thus the line due to the echo shows up against this background even for quite small signal/noise ratios. This affords a powerful aid to detection (3) in a similar manner to the way in which integration, due either to afterglow of a cathode-ray tube screen or to persistence of vision, aids detection in radar displays. A limitation of the chemical recorder is the relatively slow speed at which the stylus can traverse the paper, owing to the mechanical drive (°). A purely electronic device like a cathode-ray tube can give immensely faster scans. But for underwater acoustic purposes this limitation is often not serious owing to the low velocity of propagation of sound. Nevertheless, it is not always realized that there is a serious limitation of performance in that, with

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(°) The speed of traverse can be increased considerably, as in a « Mufax » Picture Transmission recorder, by using a wire, wound in the form of a single turn of a helix, around a bar of length equal to the paper width. The bar is mounted at right-angles to the direction of motion of the paper, and the wire, acting as a stylus, is just in contact with the paper. As the bar rotates the point of contact of wire and paper moves rapidly across the paper and hence the system is capable of much greater traverse velocities than the normal recorder. However the resolution is poor, i.e., the effective stylus length is greater and no improvement is achieved in effective stylus time (see Section 2).

the slow traverse coupled with a stylus point of finite size, it is quite possible for the acoustic pulse to be short compared with the time occupied by the stylus in traversing its own length.

This condition is most likely to arise in systems in which the reverberation energy (i.e., the back-scattering of acoustic energy from discontinuities in the water) exceeds the noise level, since it is possible to reduce the reverberation energy by shortening the pulse duration. Hence if the target amplitude is unaffected by this shortening, as is often the case, then an improvement of signal/background ratio occurs. It is shown in this paper that the behaviour of the recorder is similar to that of a low-pass filter, the bandwidth of which is inversely proportional to the effective stylus time T (i.e., the time occupied by the stylus in traversing its own length). The effect of a filter on the detectability of a pulse in noise backgrounds has been examined by Lawson and Uhlenbeck (2) and they have shown that a considerable loss of detectability results if the bandwidth occupied by the pulse is much greater than that of the filter. Thus, with a chemical recorder, if the duration of the acoustic pulse is less than the effective stylus time a loss of detectability results with a noise background, and a negation of the potential improvement when the background is reverberation.

1.2 *Definition of Intensity.*

Before a theoretical investigation of this problem can be made it is necessary to define in objective terms the parameter which the eye appreciates in detecting a mark on the chemical recorder trace. It is obvious that for a large surface the sensation of response at the eye due to the reduction in light received from the trace is, to a first approximation, proportional to the quantity of iodine per unit area. This will probably not apply to extremely small areas but should apply down to the limit of resolution of the eye, which is better than the limit of resolution imposed by the stylus size. The relationship between sensation and iodine per unit area is obviously not linear and will depend on a number of subjective factors which, if taken into account in this simple treatment, would only serve to confuse. Consequently the theoretical performance of the recorder is hereafter measured in terms of intensity, i.e., quantity of iodine per unit area. Subjective tests, also discussed, support this simplification.

2. — THE TIME AND FREQUENCY RESPONSE OF THE STYLUS

An insight into the way in which a trace is built up when a pulse is applied can be obtained by reference to Figure 1. Applying a pulse of duration τ gives a mark on the paper whose intensity distribution along the direction of stylus motion assumes a trapezoidal form. As τ tends to zero, so the time-length of the mark tends to T (T is the time-length of the stylus i.e., its physical length divided by its velocity). Thus if a unit impulse (°) were applied, the time-length of the mark would be T and its intensity $\frac{1}{T}$. Any applied waveform f(t) can be considered as a series of unit impulses and hence by application of the super-position theorem it

(°) A unit impulse is a pulse of very small duration but very large amplitude whose area however is of unit energy.

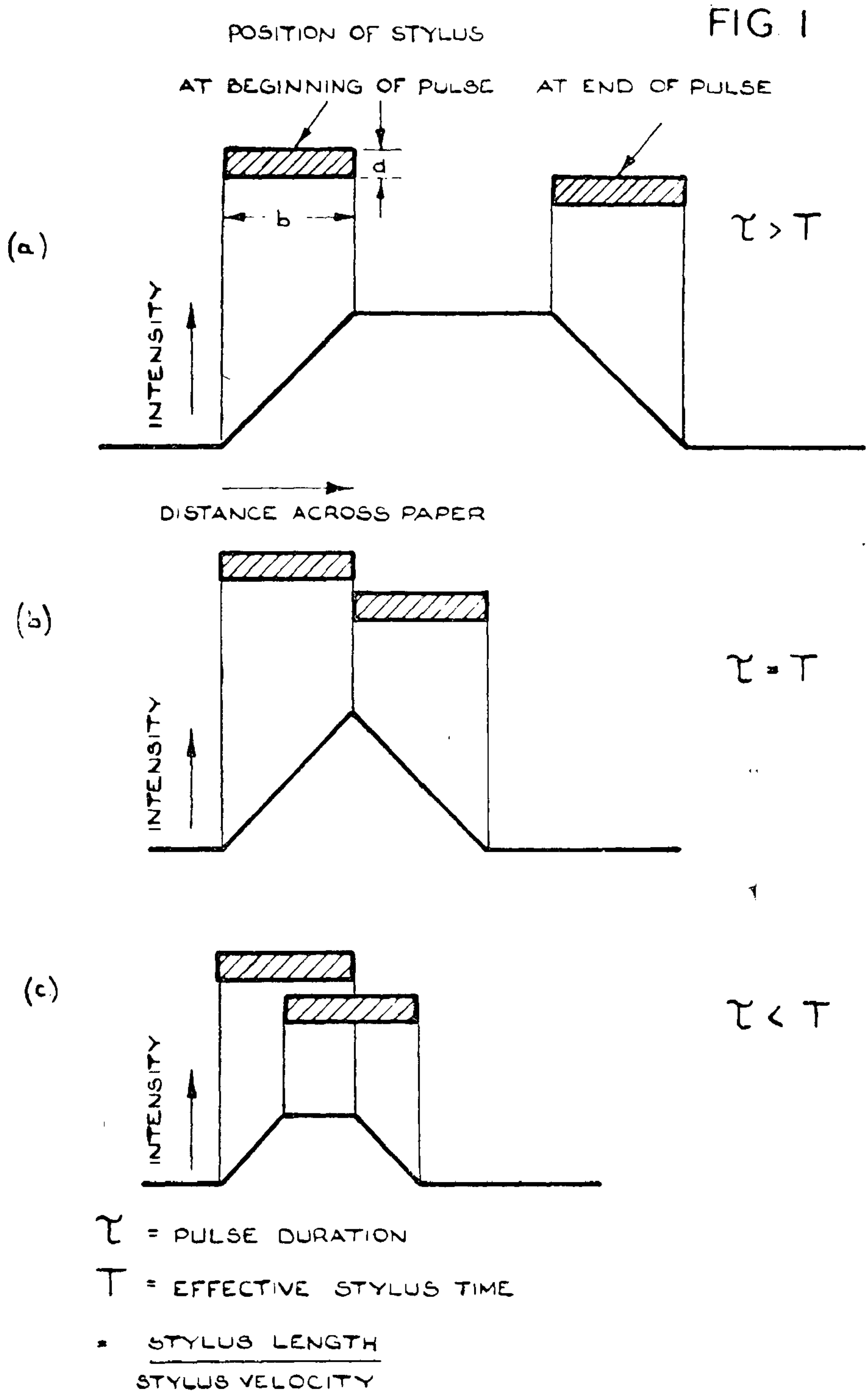
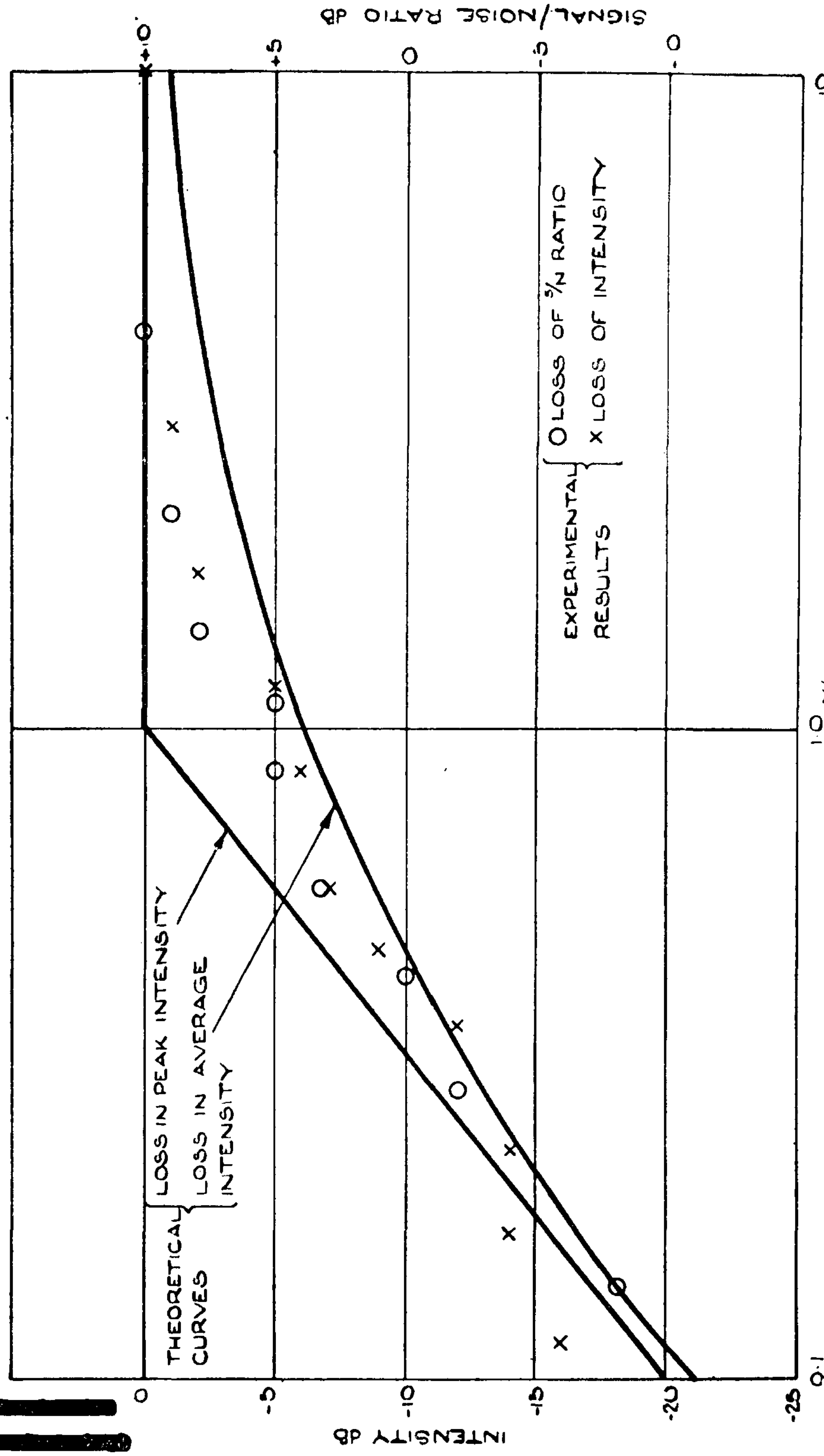


FIG. I. SHOWING HOW THE INTENSITY DISTRIBUTION OF A TRACE VARIES WITH PULSE DURATION.



[redacted]

FIG. 2. LOSS OF INTENSITY WITH DECREASING PULSE DURATION.

can be shown that the intensity of the mark at the trailing edge of the stylus is proportional to $\frac{1}{T}\int_{t-T}^{t} f(t)\,dt$. The effect of this is that the stylus smooths out the more rapid fluctuations of f(t) and hence is analagous to a low-pass filter. Having defined the time response, then by application of Fourier's theorem the frequency response can be determined. This is shown in Appendix 1 to be a $\left(\frac{\sin x}{x}\right)$ curve with the first zero at $f = \frac{1}{T}$. The 3 db point on the frequency response curve is at a frequency of approximately $\frac{1}{2T}$ and thus we can say that the stylus acts as a low-pass filter whose 3 db bandwidth is $\frac{1}{2T}$.

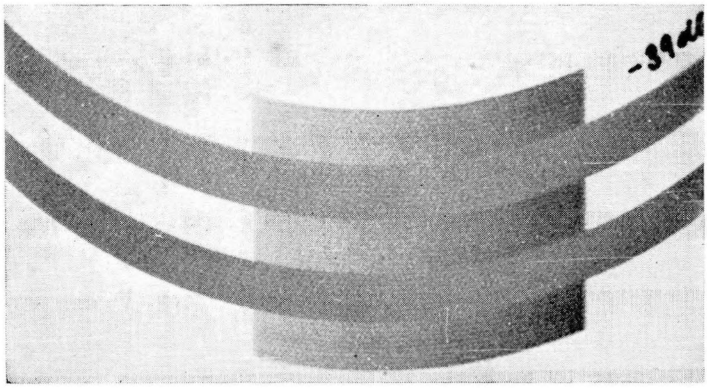
To establish the validity of these arguments some subjective experiments were made to determine the effect, on intensity of the mark, of varying the pulse duration. From Figure 1 it is possible to derive theoretical curves representing this effect and since the result depends on the relation between τ and T, and not their absolute values, it is possible to draw a single curve to represent all cases, by using a scale of $\frac{\tau}{T}$ for the abscissa. The intensity of the mark can be considered as its maximum or its average over the width of the mark, and curves for both are plotted in Figure 2. [The calculations from which the average curve was derived are shown in Appendix 2]. The other points marked on Figure 2 are experimental results discussed in the next section.

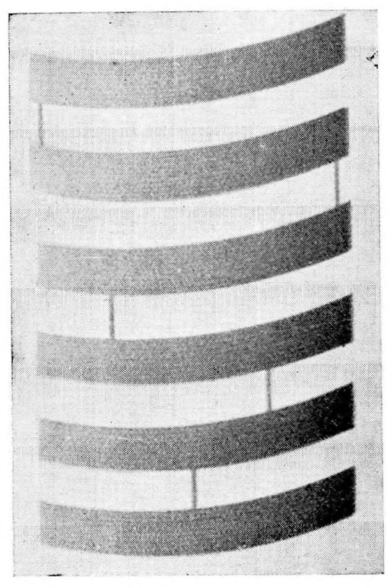
3. — EXPERIMENTAL RESULTS

3.1 *On the Variation of Intensity with Pulse Duration.*

In order to obtain an experimental confirmation of these results some subjective trials were made in which the loss of marking intensity due to pulse duration was measured by comparing the intensity of the mark from a pulse, with a trace from a D.C. calibrating voltage; the difference between the pulse voltage and the calibrating voltage gave the loss due to pulsing. It was soon found that a poor match of the pulse and calibration marks appeared to be quite good until compared with a better one, and that the selection of the best match from several comparisons was essential to the attainment of consistent results. A convenient way of doing this was to display the same pulse in several positions adjacent to a calibrating trace, whose intensity varied across the paper (see Figure 3).

To obtain a datum for the experiment a calibrating trace was made and then adjacent to it an « infinitely-long pulse » i.e. D.C. was displayed. The amplitude of this was adjusted until a match was obtained at the centre of the calibrating trace, as shown in Figure 3(a). A pulse of some known duration was then displayed in various positions adjacent to the calibrating trace as shown in Figure 3(b). The pulse amplitude was adjusted by means of an attenuator so that the best match was obtained at the centre position. Interpolation from a trial pattern usually enabled the correct adjustment of the attenuator to be made at the second attempt. The





(a) MATCHING D C TO A WEDGE

(b) MATCHING A SHORT PULSE TO A WEDGE (2 m.S PULSE. OF AMPLITUDE 4 dB ABOVE DATUM, MATCHES CENTRE OF WEDGE)

[redacted]

FIG. 3.

decrease in attenuation necessary to bring the short pulse intensity back to datum level was a measure of the marking loss due to pulse duration.

The results of these experiments are marked on Figure 2 and it can be seen that they agree with the curve of average intensity more nearly than that of peak. Note that this is the average intensity taken over the width of the mark and not over the whole width of the paper.

3.2 *On the Variation of Threshold Detection with Pulse Duration.*

A further set of subjective experiments were carried out to find the effect of pulse duration on the signal/noise ratio required for threshold-detection i.e., the signal/noise ratio at which the signal is just distinguishable from the background.

Conditions of the experiment were as follows:

Receiver bandwidth = 6 kc/s.

Length of complete trace on recorder (in direction of motion of paper) = 1 inch.

No. of single traces in this length = 120.

Effective stylus time = 0.7 mS.

The pulsed signal and noise were combined in a known ratio, amplified by the receiver, detected and fed to the recorder stylus. The results obtained (shown in Figure 2), are for one observer only, and therefore should not be taken too literally, but rather as an indication of the tendency. It has been confirmed in Section 3.1 that the recorder behaves as a low pass filter, the bandwidth of which will be fixed provided the stylus speed and size remain unaltered. Hence the noise in the output will be independent of variations in pulse duration. However, the maximum signal amplitude in the output will depend on the relation between the pulse duration and the effective stylus time, and will follow the curve for loss of intensity shown in Figure 2. Thus since the noise remains constant the results for loss of detectability should coincide with those for loss of intensity, as indeed, within experimental limits, do the results shown in Figure 2.

4. — CONCLUSIONS

The main conclusion from this work is that if the effective stylus time is longer than the pulse duration then a degradation of performance occurs. To overcome the degradation it is necessary to decrease the effective stylus time, and this requires a smaller stylus and/or an increase in stylus velocity both of which are obviously limited by mechanical considerations. Hence the use of a recorder in applications requiring short pulses is definitely limited. When the pulse duration is shortened in order to reduce reverberation energy, the improvement to be gained in signal/background ratio will be counterbalanced by the degradation discussed above if τ is less than T. Since when τ is less than T the recorder is acting as a filter of insufficient bandwidth to pass the pulse without distortion the effect is similar to having too narrow a receiver bandwidth. A fuller discussion of the effect of receiver bandwidth on reverberation-limited detection can be found in Reference 4.

A second point of interest derived from the results of Section 3.2 is that the eye appears to register the average intensity across the width of the mark rather than the maximum and is detecting by the increase in average intensity in that part of the trace where the signal is present This is in contrast to detection on an A-scan type of display where peak amplitude is almost certainly the basis of detection.

However, Lawson and Uhlenbeck (2) show that even on an A-scan there is an optimum length of pulse, supposedly due to the inability of the eye and brain to sort out information that is spatially too close.

5. — ACKNOWLEDGEMENT

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APPENDIX 1

Determination of the Frequency Response of the Stylus

If an impulse function of unit area is applied to the stylus then the response plotted against time is a rectangular pulse of height $\frac{1}{T}$ and duration T

i.e. $F(t) = \frac{1}{T}$ for $-\frac{T}{2} < t < +\frac{T}{2}$

$= O$ for all other values of T

N. B.: Zero time is taken at the centre of the pulse for convenience.

$$G(f) = \int_{-\infty}^{+\infty} F(t) \, . \cos \omega t \, . \, dt$$

$$= \int_{-\frac{T}{2}}^{+\frac{T}{2}} \frac{1}{T} \, . \cos \omega t \, . \, dt$$

$$= \frac{2}{T}\,\frac{\sin \frac{\omega T}{2}}{\omega} = \frac{\sin \frac{\omega T}{2}}{\frac{\omega T}{2}} = \frac{\sin x}{x}$$

$$\text{where } x = \frac{\omega T}{2}$$

$$G(f) = O \text{ when } x = \pi$$

$$\text{i.e. when } f = \frac{1}{T}$$

APPENDIX 2

Average Intensity of the Trace Due to a Pulse of Duration τ

The shape of the intensity of the trace plotted against time or distance along paper is shown in Figure 1. The average intensity can be expressed as

$$\frac{\text{area of trapezium}}{\text{base length of trapezium}} = \frac{1}{2}\left\{\frac{\text{base} + \text{top}}{\text{base}}\right\} . \text{ height}$$

for $\tau < T$

$$\text{average} = \frac{I\,\tau}{2\,T}\left(\frac{T + \tau + T - \tau}{T + \tau}\right) = \frac{\tau}{T + \tau}\, I$$

where I = maximum intensity reached when $\tau > T$

for $\tau > T$

$$\text{average} = \frac{I}{2}\left(\frac{\tau + T + \tau - T}{\tau + T}\right) = \frac{\tau}{T + \tau}\, I$$

thus the same expression applies over the whole range and can be stated as *loss of average intensity* $= 20 \log (1 + \frac{T}{\tau})$ *db.*

[The factor of 20 is because the intensity is proportional to current in the input.]