Capture and analysis of joint vibration

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CAPTURE AND ANALYSIS OF JOINT VIBRATION

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The diagnosis of joint pain is difficult and surgeons often resort to invasive methods of investigation. The technique of capturing joint vibration emission is suggested as a likely aid to diagnosis and some methods of analysis are described.

1 INTRODUCTION

Generally, the cause of a patient's suffering from painful joints can be found by examination, and the case history. An x-ray can reveal signs which confirm the diagnosis. However, taking the knee as an example, these methods are not sufficient for one in five cases. If some meniscal injury is suspected an air arthrogram is often performed. This is an x-ray technique where air and a contrast medium are injected into the joint space, to outline the joint space. When the diagnosis is complicated a more invasive operation, such as Arthroscopy, is carried out. A small telescope is inserted into the joint space and allows direct viewing of the surfaces, usually requiring general anaesthetic. An exploratory operation (Arthrotomy) is only practical if no other test can explain the condition, and it also carries the risks of infection and anaesthesia.

Indeed none of these methods are totally objective and non-invasive.

2 HISTORY OF JOINT VIBRATION EMISSION

There have been several attempts to improve diagnosis of joint conditions by examining the vibration emission. Dr Blodgette, in 1902, was first to apply a stethoscope to the knee and in his publication he described how dots and dashes were used to record and describe the types of sound he heard[1]. In 1913 Bircher[2] went as far as to say that each type of injury had a distinctive sound emission and Walters, in 1929, suggested that certain noises could be detected even before any other symptoms were apparent[3]. From 1933 when Erb recorded sounds on a graph[4], various "joint prints" have been produced.

By attaching sensitive microphones to the joint, some objectivity was introduced, and further graphical representations produced. Nevertheless diagnostic accuracy was so low that no valid clinical tool has yet been produced.

This development has continued with our examination of the microphone detection system which uncovered several shortcomings. Human joint emission was found to be outside the frequency range of microphones, and, because of coupling problems, and background noise,

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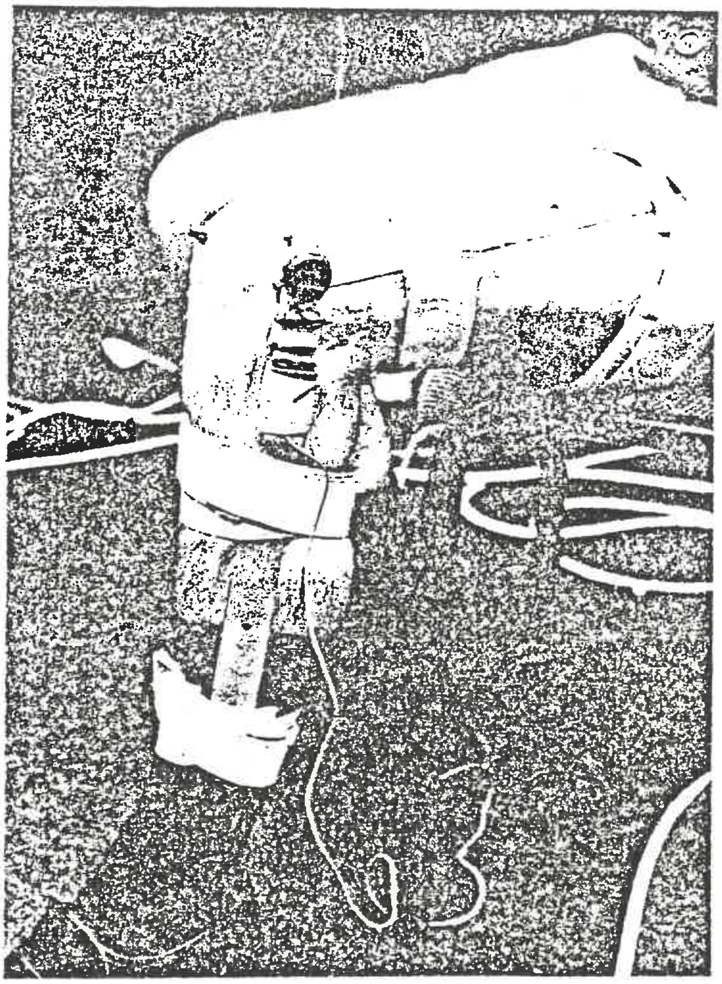


FIGURE 1

This photograph shows a patient's knee under interrogation by a single tiny accelerometer taped on to the kneecap. The goniometer which is fitted consists of a potentiometer, hinged at the knee, having 2 shafts, belted to the leg above and below the knee.

microphones were considered inadequate[5]. We have shown accelerometers to be superior and we have found that they overcome all of the problems associated with microphones[6].

3 CAPTURE AND ANALYSIS

3.1 Recording system

Our present set up for recording knee joint vibration is an accelerometer/goniometer system (figure 1) with each accelerometer taped to the joint. The goniometer simultaneously records joint angle so that any episode of emission is referred to an angle. Signals from the transducers are amplified and then recorded on an FM recorder.

The recording is made as the patient flexes and extends his leg at approximately one complete cycle (flexion-extension-flexion) every 20 seconds. This rate has been chosen arbitarily to maximise grating and crepitus from the joint.

3.2 The playback system and the IEEE/488 interface

The tape recorder is initially played into an ink-jet recorder, providing a reference of the signals which are present in the joint cycle, albeit a compressed picture (figure 2). Sections of interest can be indentified from this reference and captured on a narrow band spectrum analyser (Bruel & Kjaer 2031) for analysis. One channel of the tape recorder is digitised by this machine and displayed. The trigger point, analog/digital voltage range, and sampling frequency are all push-key selectable, and the fourier transform of the captured window is available. However, the Bruel & Kjaer machine limited us, for several reasons:

(a) Once captured; an interesting section may not be digitally stored.
(b) The scales of the machine are not in acceleration units
(c) Apart from the frequency transform no other analysis technique is possible.

To overcome these limiting factors a link between this machine and an Apple 11 microprocessor has been established. Custom programming of the Apple was required to drive the adaptor card. Figure 3 shows the flow chart for transfer of a time signal to and from the B & K machine. The adaptor chip must first be initialised (slot calculated, 9914 reset, clear interrupts) before the B & K is addressed as a listener. Then various control codes are sent from the micro. One will prepare the B & K for output. Another allows the settings to be fixed; such as sampling frequency and A/D range. A third control code is used for data transfer to the B & K machine. One advantage of this mechanism is that complicated sections of signal may be further divided into sections, and a transform of each can be obtained. Alternatively, a 'clean-up' procedure in the apple is used to remove unwanted low intensity signals, thus increasing the transform accuracy.

3.3 The signals

It is by reference to the complete joint print produced on the ink-jet recorder, that sections can be most easily captured, for a more detailed study. Using the IEEE interface a calibrated drawing, such as the patellar click (figure 4), can be produced on the micro. Furthermore the decay rate can be calculated by fitting an exponential to the curve. This will give a measure of the patella's damping effect on the signal. A fairly simple integration technique yields the velocity pattern for a patellar click (Figure 5). In this case some indication of displacement was calculated by integrating twice (Figure 6). This gives an estimate of how much the knee cap moves, during a patellar click.

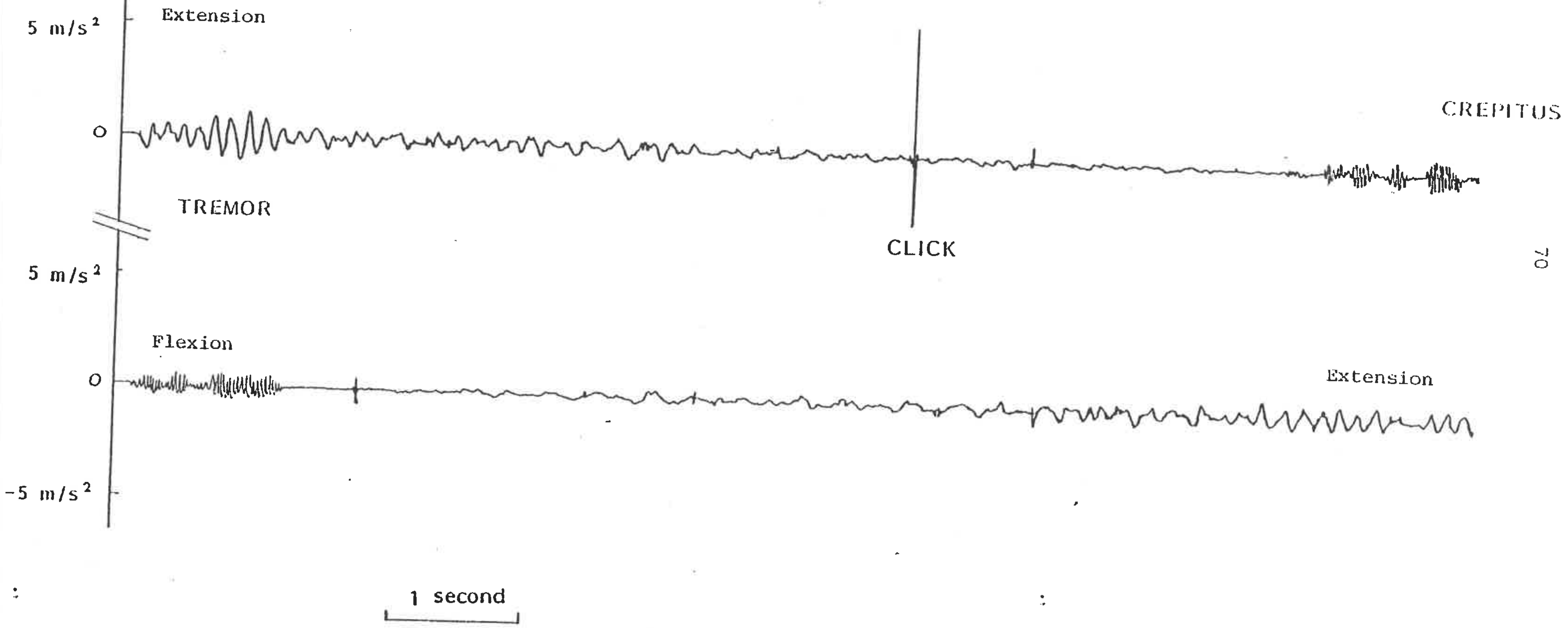
Other types of signals which have been identified are crepitus (Figure 7) and tremor (Figure 8). Tremor is produced by the muscular control system which vibrates at 7 Hz at full extension. Crepitus is a complex sinusoid which we consider to be related to roughness of the joint surfaces.

We consider these signals to contain joint condition information and, by analysing them in various ways, we hope to extract this information to enhance clinical diagnosis.

FIGURE 2

COMPLETE JOINT PRINT

OUTPUT FROM INK JET RECORDER



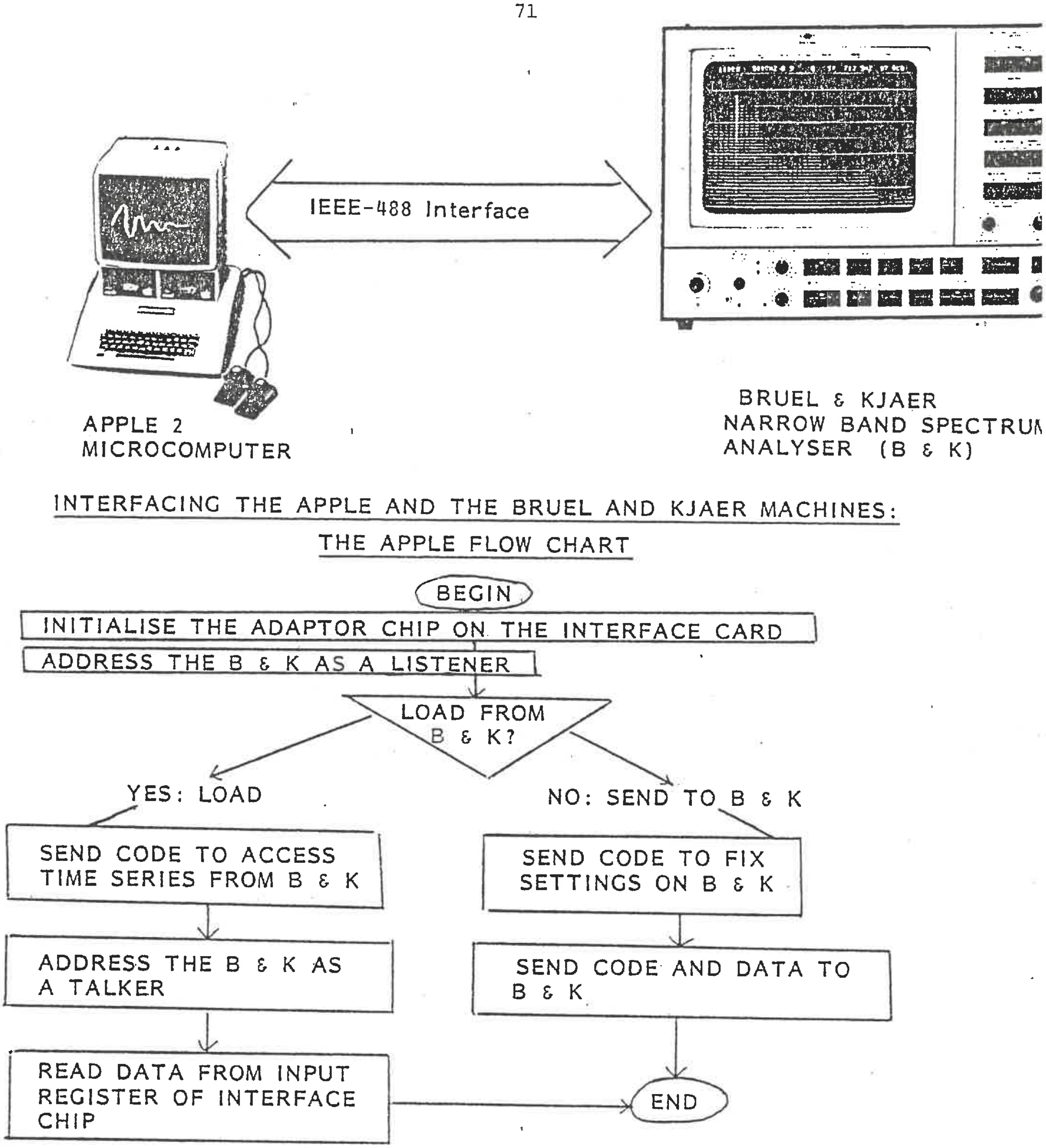


FIGURE 3

Flowchart for transfer of a time signal between the Bruel and Kjaer spectrum analyser and the Apple 2 microcomputer

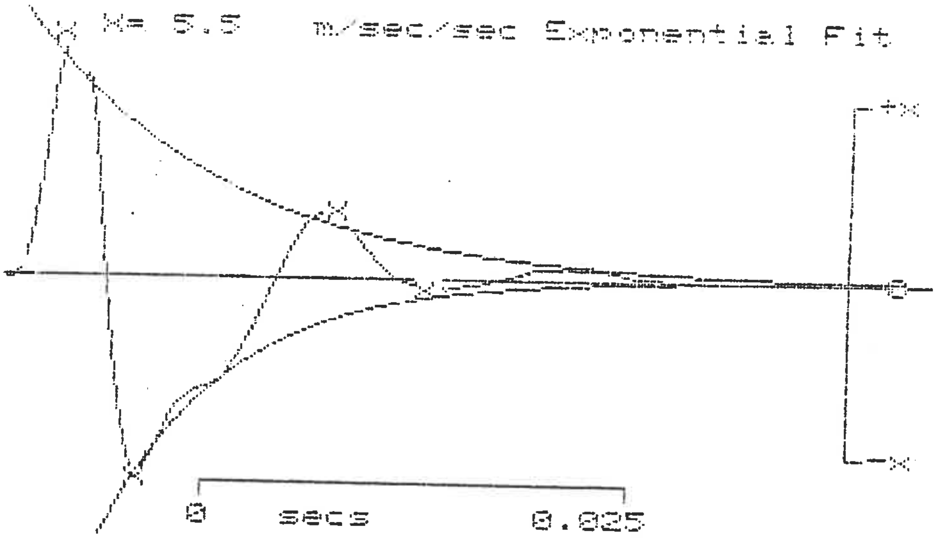


FIGURE 4

A calibrated drawing of a patellar click, showing exponential curve fitting to the envelope of the decay

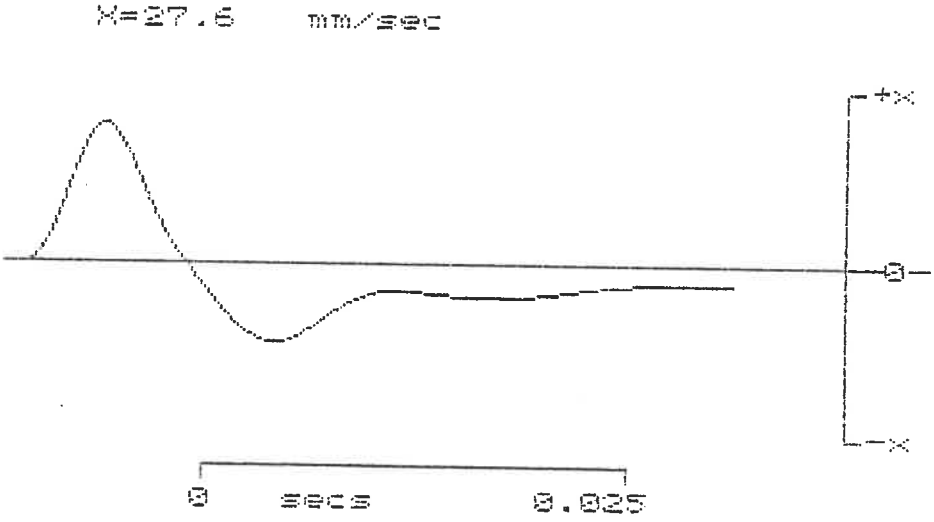


FIGURE 5

The velocity pattern for a patellar click found by integration of the signal in Figure 4

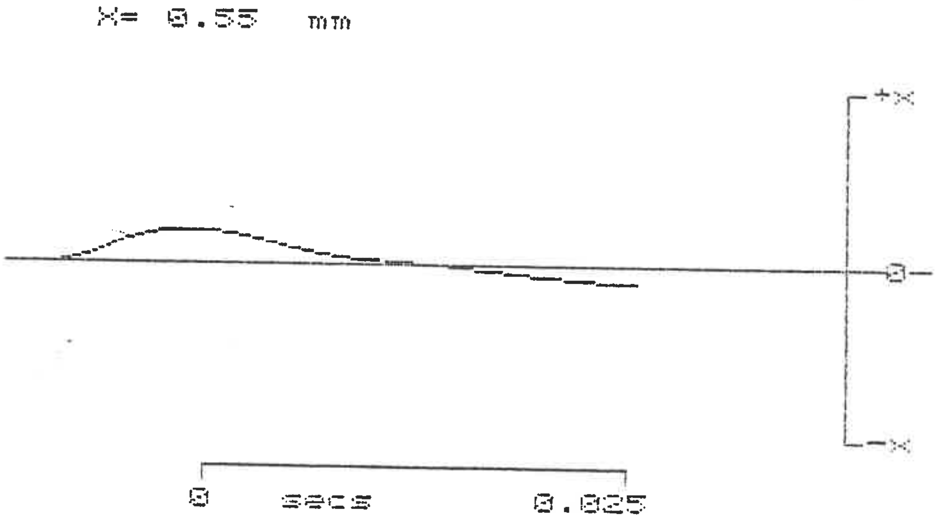


FIGURE 6

The displacement pattern found by integration of the velocity pattern

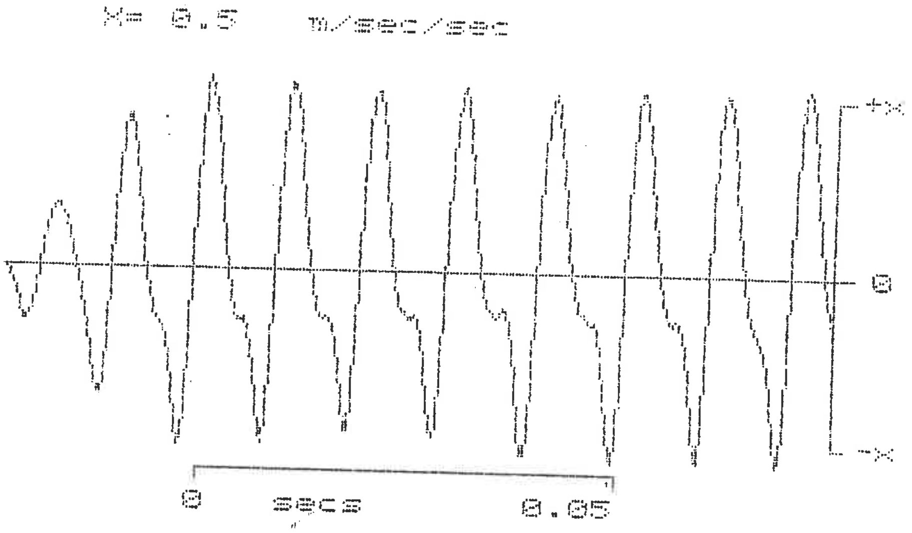


FIGURE 7

Initial phase of a crepitus wave. The amplitude of this ma give a measure of joint roughness

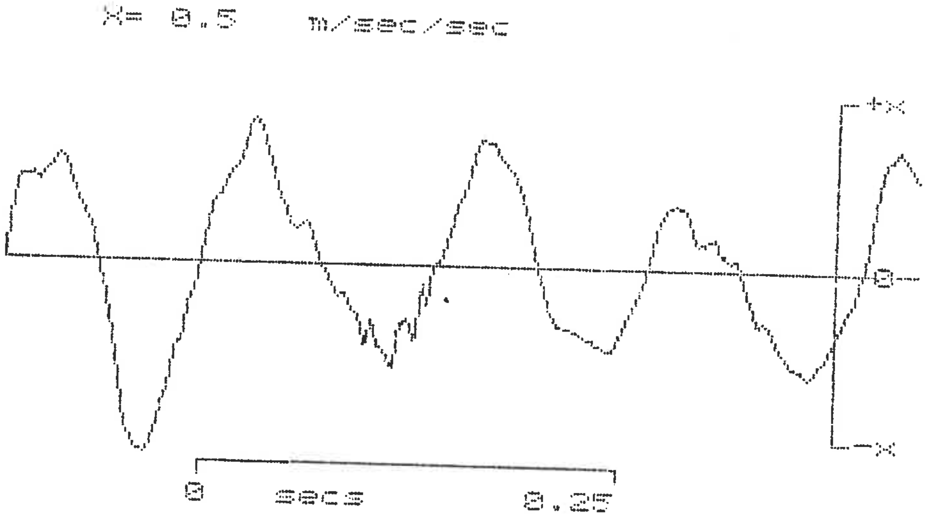


FIGURE 8

A section of a tremor wave;predominating at full extension (leg held straight)

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