A Self Calibrating Vibration Meter for Measuring Displacement Amplitudes of Machine Foundations

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Introduction

VIBRATION pick-ups can be classified into three different types, depending on whether the output is a direct function of the acceleration, velocity or displacement of the vibrating body under investigation. While the former two have the advantage of employing conveniently compact piezoelectric or electro-magnetic transducers, they suffer from the disadvantage that to obtain the value of the displacement, it is necessary to use integrating network that introduce large and uncertain attenuation to the processed signal. The uncertainty arises mainly from the drift of the values of the components with time. It, therefore, becomes obligatory to check the calibration of the instrument periodically against a standard. A more serious objection can be posed, the time constant of the integrating network must be properly matched to the frequency of vibration for obtaining a faithful integrated output—a condition seldom met in commercially available instruments.

Thus, for simplicity of operation and accuracy in displacement amplitude measurements, it is preferable to use a displacement sensitive transducer directly. Among the various possibilities, a capacitative transducer producing a frequency modulated r.f. output was selected as it gave high sensitivity (Harris & Crede, 1961) combined with low stray effects on the signal. An absolute calibration device was also incorporated, which eliminated the need of standard vibration tables.

Mechanical Design of the Transducers

THE VERTICAL PROBE

In all vibration transducers a reference body is employed, which, due to its inertia tends to remain at rest, permitting the measurement of the relevant parameter with respect to it. In the present instrument it takes the form of a massive square plate (10 cm × 10 cm) fixed at one end of a light aluminium beam supported on a ball bearing mounted axle near the other end, the weight of the plate being counterbalanced by a

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spring as shown in Figure 1. The mass distribution is highly asymmetric about the fulcrum, resulting in the large moment of inertia essential for maintaining the reference plate at rest. This plate forms the upper half of a parallel plate condenser the lower plate of which is fixed to the floor of the transducer by a device to move it through calibrated vertical distances, as shown in Figures 2 (*a*) and 2 (*b*). In the pulled out position of the shaft as shown in Figure 2 (*a*), the worm engages with the spur gear on top, and one rotation of the shaft moves the plate through a distance of 0·02 mm. In the pushed-in position, the worm is disengaged as shown by the dotted outline in plan, Figure 2 (*b*), and the bevel gears mesh together, giving a 1 : 1 drive ratio. One rotation of the shaft in this position moves the plate through 1 mm.

A clamp is provided for avoiding transit damages and the spring tension can be relieved when the instrument is not in use.

HORIZONTAL PROBE

Except for the method of suspension, the horizontal probe is a replica of the vertical probe turned through a right angle. Here the reference plate is constrained to move in a horizontal plane, and thus the restituting force of the spring is not required to support the weight of the plate, allowing the use of much weaker spring strips [see Figures 3 (*a*) & 3 (*b*)] and much shorter beam length for obtaining a long natural period of oscillation of the suspended system. The period is kept at about 2 seconds for both the vertical and the horizontal probes.

Electrical Design of the Transducers

The two parallel plates of the transducer form a capacitor which is incorporated in the tank circuit of an electronic oscillator. The output frequency of the oscillator depends on the separation between the plates. Due to vibration the separation and hence the capacitance of the plates undergoes a periodic change, resulting in a frequency modulation of the output, the degree of modulation depending on the vibration amplitude.

The oscillator is located within the transducer casing itself, so that frequency variation due to changes in the lead wire configuration do not occur. It employs a Hartley-type transistor circuit (Figure 4), modified to permit grounding of one end of the tank circuit. This minimises frequency shift due to stray effects. A common emitter amplifier stage follows the oscillator to provide isolation and some voltage gain. The final output of the transducer is a 6 volts peak to peak sinusoidal signal.

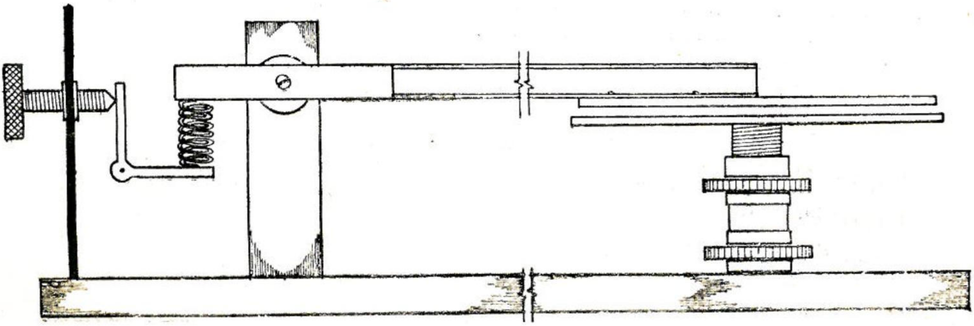

FIGURE 1 : Suspension arrangement of vertical probe.

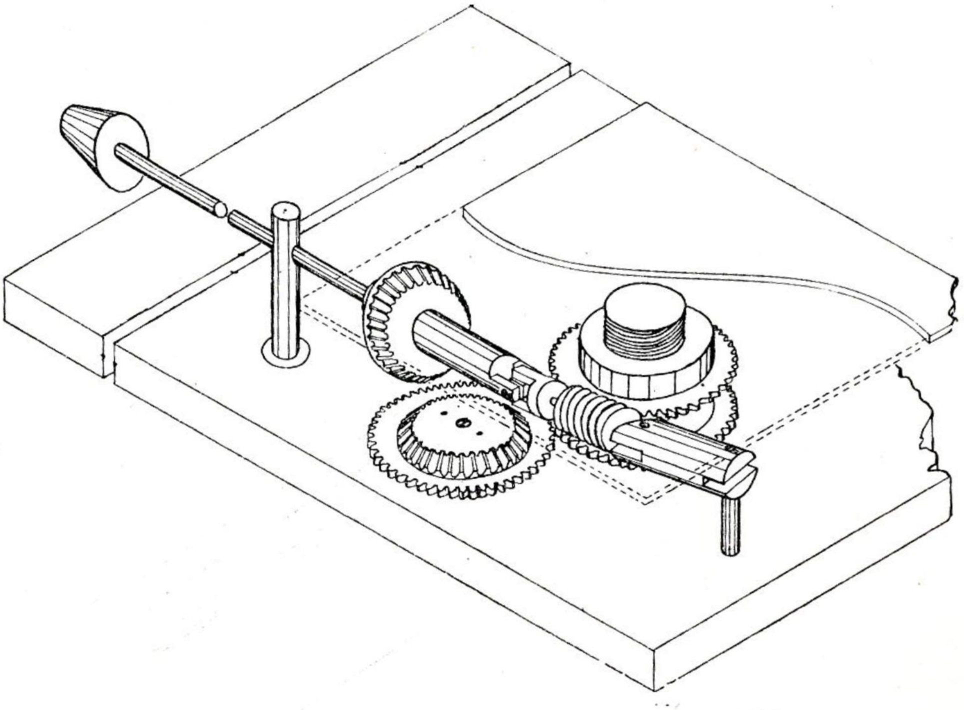

FIGURE 2 (a) : Isometric view of the calibration device.

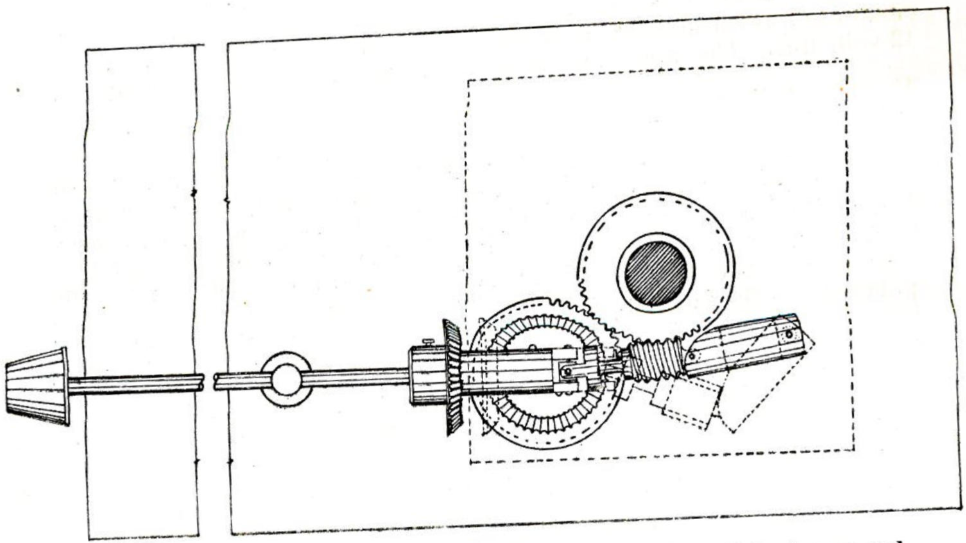

FIGURE 2 (b) : Plant of the calibration device, dotted outlines of level gear and worm are for pushed-in position.

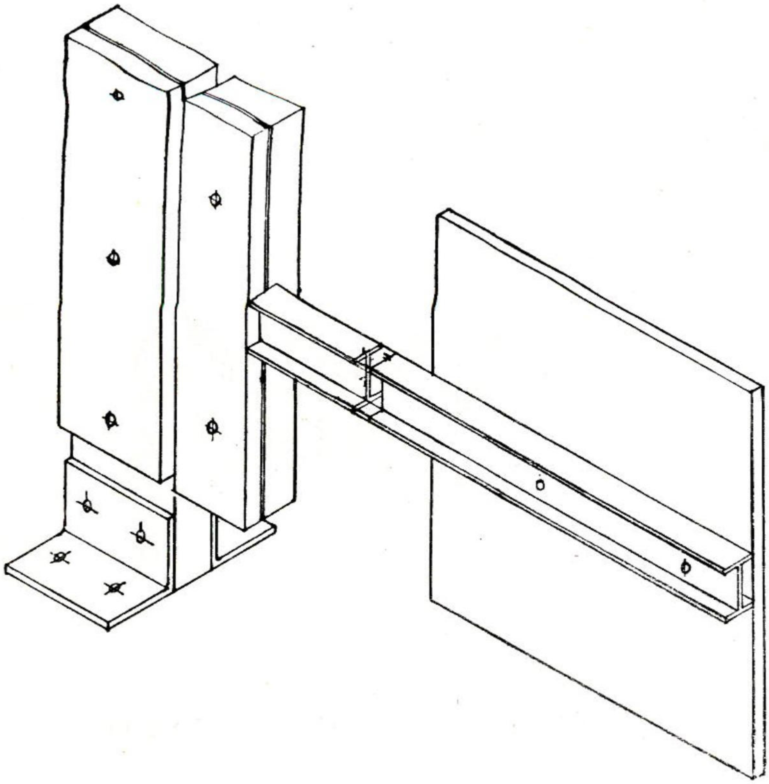

FIGURE 3 (a) : Method of suspension of horizontal probe.

The centre frequency is chosen at 500 kHz, so that standard i.f. transformers of radio receivers can be employed in the later stages. The oscillator and isolating amplifier stages are supplied with a zener-stabilized 12 volts line. The input and output leads are taken to an octal socket.

The Signal Processing Unit

The signal processing unit is designed in such a way that it can either be used normally for measuring vibration amplitudes, or as a double channel instrument for comparing the phases of two independent inputs from two transducers. The circuit diagram is shown in Figure 5. In the first mode, with the selector switch in position 1, the input amplifier is a pentode, a 6AU6, which feeds into another 6AU6 used as a limiter stage. Signal demodulation is done by a Foster-Seeley type discriminator circuit (Foster & Seeley, 1937) employing silicon diodes. It produces a voltage proportional to the frequency deviation from the centre. The time constant of the RC network of the discriminator is chosen at 10^{-4} sec., which is sufficiently long to filter out the 500 kHz centre frequency, but is short enough to be able to reproduce the modulating signal, *i.e.*, the vibration pattern up to a frequency of 1kHz, which is more than adequate for any civil engineering application. The output of the discriminator is fed to a BNC socket for oscilloscopic observation, and also to a peak detector circuit. The peak detector has a

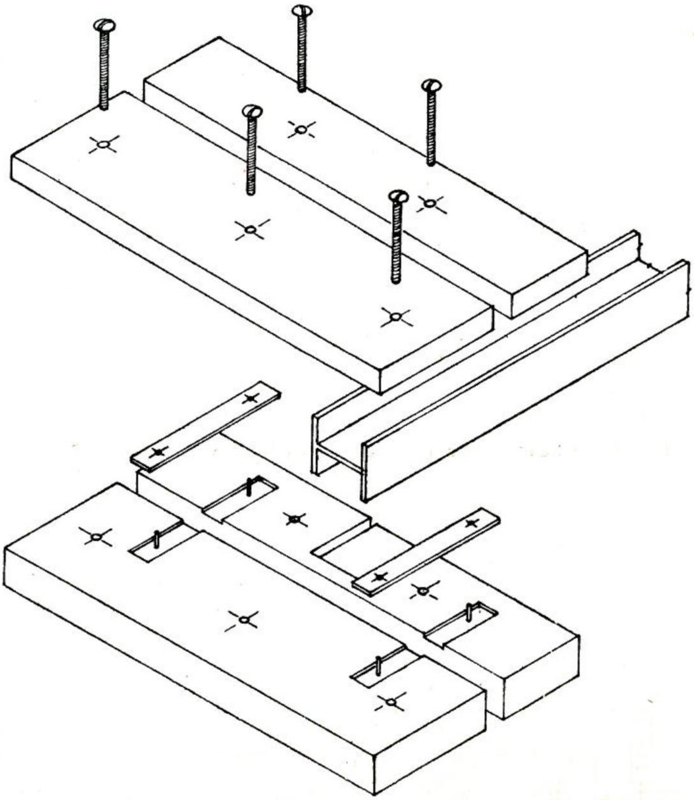

FIGURE 3 (b) : Exploded view of the support.

time constant of 0·5 sec., so that the peak reading is effectively retained at the lowest design frequency of 4 Hz. For proper operation the discriminator is biased at —4·5 volts from an auxiliary circuit and the final output is fed to a D.C. V.T.V.M., formed by a double triode ECC 83 and a 500 microamp. f.s.d. panel meter. The meter sensitivity can be controlled by a variable series resistor.

For the double channel operation use for phase comparison purposes, the selector switch is kept in position 2, when the two triode sections are connected as signal preamplifiers, both the pentodes now functioning as limiters. A second discriminator now comes in the circuit, and the outputs from both the discriminators are available at two BNC sockets for oscilloscopic display.

The unit is powered by a stabilized 220 volts D.C. supply of an unorthodox design (Figure 6), which achieves economy in space and cost. The conduction tube is an EL84, but the single stage high gain error voltage amplifier is made of a high voltage n-p-n silicon transistor CIL622 in common emitter configuration, its emitter being maintained at a reference voltage of 110 volts obtained by putting two NE51 neon tubes in series. This eliminates the use of bulky voltage regulator tubes, the

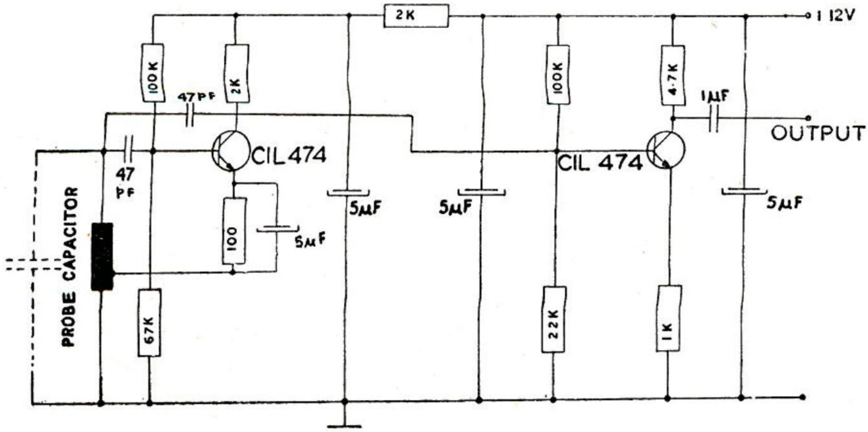

FIGURE 4 : Circuit diagram of the oscillator and amplifier in probe casing.

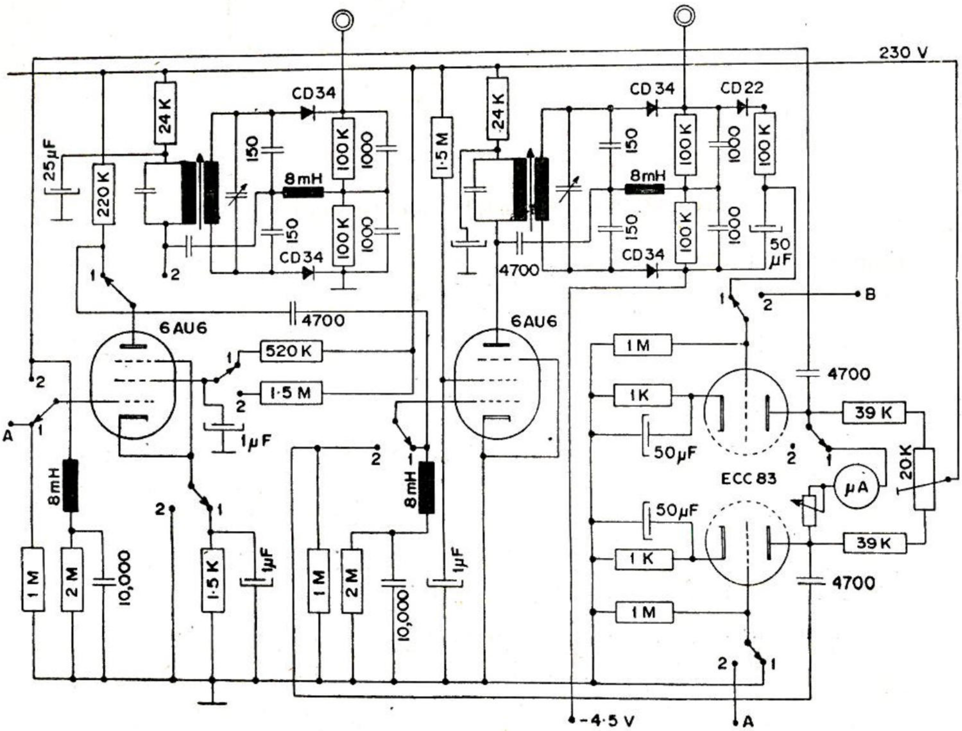

FIGURE 5 : Circuit diagram of the signal processing unit. Point A represents input from Channel 1, point B is input from channel 2. All capacities are in F unless otherwise stated.

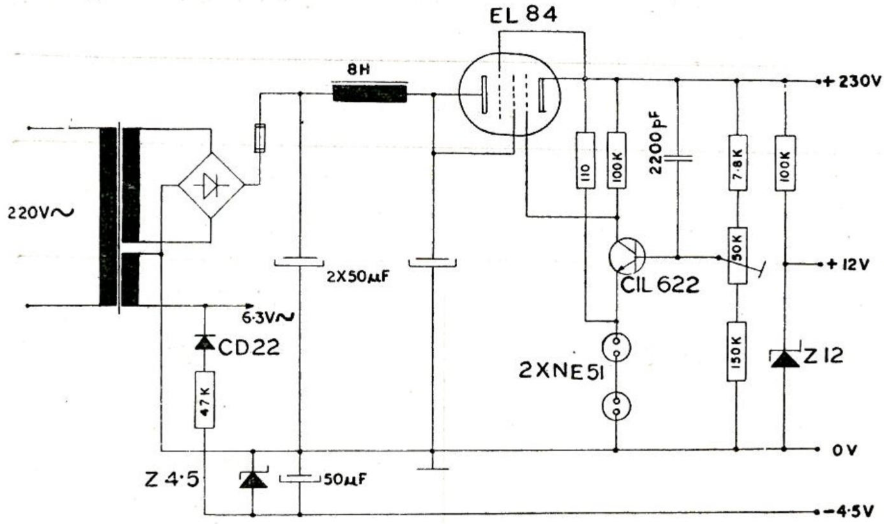

FIGURE 6 : The power supply unit.

minute current admitted by the neon tubes being adequate for the satisfactory operation of the transistor. At the same time it gives better regulation than zener diodes being much less temperature sensitive. One of the tubes is placed on the front panel as a H.T. indicator lamp.

Operation

The transducer is placed on a stable base first, levelled and unclamped. The spring tension is then set to the proper value to counterbalance the beam. The electrical link between the transducer and the signal processing unit is connected, and the unit is switched on. The plate separation is adjusted by the knob on the geared shaft to produce zero deflection on the meter. The beam is clamped and the transducer is placed on the foundation to be tested. After levelling afresh, the beam is unclamped, and the meter deflection is adjusted to a convenient value by setting the series resistor. The probe is then brought back to the stable base and levelled, when the meter shows zero reading. The position of the lower plate is then adjusted by means of the knob, till the meter reading equals the reading obtained for the vibrating foundation. The required displacement of the plate gives directly the vibration amplitude. For, previously, the meter held the reading corresponding to the peak of the separation between the plates as measured relative to the equilibrium (zero reading) position, *i.e.*, to the displacement amplitude. Thus, the self calibrating feature of the instrument is demonstrated.

Performance

With the instrument set for the maximum sensitivity, a displacement of the lower plate through 0·02 mm causes a meter deflection of 100 microamp. In the following table, the readings obtained by the instrument are compared with those obtained by a standardised velocity pick-up.

Amplitude in mm	
Value from standard velocity pick-up	Value from the present instrument
0·025	no indication
0·035	0·035
0·042	0·04
0·08	0·08
0·25	0·25
0·42	0·40
0·70	0·72

The weight of the vertical probe is about 5 kg and that of the horizontal probe is about 3 kg. Compared to the weight of an average model foundation for field investigation to say nothing of actual machine foundations, this is quite negligible, and no question of alteration of vibration mode due loading by the probe can possibly arise.

The possibility of using the same probe in two different positions for measuring vertical and horizontal vibration modes was considered. A trial was indeed given by using the vertical probe in such a manner, that the arm was suspended vertically, with the spring tension reduced to zero, and attempting to measure the horizontal vibration amplitude. But it was found that in such cases it was difficult to keep the probe head rigid with the table vibrating even with a small amplitude. It was, therefore, decided to design a separate probe for measuring horizontal vibration as explained earlier.

For extremely small amplitudes of vibrations, the friction in the ball bearing caused the vibration to be transmitted to the suspended system in the vertical probe and vitiate the readings. A knife-edge pivot is presently being tried out and may eventually provide a better method of support.

Applications

In the single channel mode of operation, the instrument can be used in measuring vibration amplitudes of existing machine foundations, in determining the resonance positions in various modes of vibration of foundations in conjunction with a variable frequency mechanical oscillator like a Lazan oscillator and hence also soil characteristics (I.S. No. 5249, 1969).

In the double channel mode, using an oscilloscope for observations, phase and amplitude comparison of two vibrations of the same frequency can be carried out by connecting two probe heads. By using two vertical probes, placed on ground and inducing vibrations by a mechanical oscillator, the wave length of seismic waves in soil can be found out by gradually increasing the separation between the probes from zero, till the phase difference corresponds to 2π. From this the elastic constants of soil can be found out (I.S. No. 5249, 1969). By connecting one vertical and one horizontal probe placed on a foundation, the relative amplitudes of the vertical and horizontal modes of vibration of an existing machine foundation can also be determined.

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