

LONDON, METEOROLOGICAL OFFICE.

Met.O.15 Internal Report No.006.

Vibratory pressure sensor.

London, Met. Off., Met.O.15 Intern. Rep. No.006, 1977,
31cm. Pp. 10, 6 pls. Abs. p. 2.

An unofficial document - not to be quoted in print

FG2

National Meteorological Library
and Archive

Archive copy - reference only

METEOROLOGICAL OFFICE

London Road, Bracknell, Berks.



128043

MET.O.15 INTERNAL REPORT

No. 006

VIBRATORY PRESSURE SENSOR

by

A. E. Whittaker

Date : January 1977

Cloud Physics Branch (Met.O.15)

VIBRATORY PRESSURE SENSOR

Abstract

Experiments designed to control the rate of descent of a stratospheric balloon have revealed the limitations of conventional pressure sensors in discriminating very small changes in pressure.

The principles and construction of a vibrating wire pressure sensor are discussed.

Vibratory Pressure Sensor

If a wire under tension is caused to vibrate transversely, it does so at a frequency which is linearly related to the wire length and which varies as the square root of the tension.

There are a variety of ways to express the relationship mathematically, three are given below :-

$$(1) \quad f = \frac{1}{2Lr} \sqrt{\frac{T}{\pi \rho}}$$

$$(2) \quad f = \frac{1}{2L} \sqrt{\frac{G}{\rho}}$$

$$(3) \quad f = \frac{1}{2} \sqrt{\frac{T}{mL}}$$

Where

f = Resonant frequency

L = Wire length

r = Radius of wire cross section

ρ = Density of wire material

T = Tension in Dynes

G = Mechanical stress of wire in Dynes/cm²

m = Mass of wire

The properties of a vibrating wire have been used in the past to construct sensors, notably the "vibrotron" for oceanographic purposes (pressure/depth) where the active element was a diaphragm.

Aneroid barometers, as commonly used, are devices which produce movement with pressure change. The movement can be mechanically amplified by levers:

optically amplified by mirrors or sensed electrically by potentiometers, variable reluctance transformers or variable inductance coils.

It remains however a movement device and as such is subject to certain limitations. These are :- Hysteresis: changes in the modulus of elasticity of capsule material : stiction in bushes and pivots. If a "floppy" bellows with small stiffness is evacuated and coupled to a wire in such a way as to stress it in tension with relation to pressure, its frequency of vibration will be proportional to the square root of pressure as shown above. Here however, the errors inherent in conventional aneroid barometers will be reduced by a large factor as the parameter sensed is force and movement of the bellows is reduced to the very small amount that the wire stretches and shrinks under varying tension.

Where the bellows is as specified of small stiffness and used in conjunction with a tungsten wire the idealized temperature error will be $4 \times 10^{-4}\%$ per degree C.

Such a sensor has been constructed for the purpose of controlling the descent rate of a stratospheric balloon. The requirement here is for a device with a very low "noise" level (of the order of 0.01 mb) but with only a relatively short term stability at this level.

The necessary treatment of the sensor output has been discussed elsewhere (Digital Logarithmic Differentiator) sufficient to say that performance was limited by the performance of other sensors tried and that, as it is essentially a logic system requiring its input to be in the form of a varying frequency, the vibratory sensor would seem ideal for the purpose.

The sensor, as constructed, consists of an evacuated "floppy" bellows which imparts tension to a tungsten wire via a balanced beam suspended on flexure pivots. The use of a balanced beam shortens the permissible length of the sensor and careful design enables the removal of attitude sensitivity.

The wire is caused to vibrate transversely by the application of positive feedback. A piezo/electric bimorph is coupled to the wire as close to one end as is practicable and its amplified output used to drive current through the wire which is suspended between the poles of a permanent magnet at its centre.

The bimorph produces a charge proportional to the displacement. To maintain oscillation we need to feed peak current into the wire when the velocity is at a maximum. This is achieved by taking the bimorph output directly to the virtual earth point of a feedback amplifier. Assuming an initial disturbance, it will be seen that a positive feedback loop is created, causing the wire to vibrate in a plane normal to the magnetic field and at a frequency determined by the force developed by the bellows. If the phase of the current drive is reversed however, the wire is caused to vibrate at its third harmonic. This makes for easier and faster discrimination of small changes, indeed in the later versions of the sensor a further multiplication is performed by simple logic circuitry.

The early version of the drive circuit was merely a high gain amplifier which saturated giving a square wave drive. It was found that at high tensions of the wire this was reasonably effective giving a linear plot of f^2 vs. P but at lower tensions its performance was unpredictable and not very effective.

Stroboscopic and microscopic examination revealed that at lower tensions (particularly) the wire did not vibrate in a plane normal to the magnetic field but in a more complex and variable mode more akin to a skipping rope or rotating letter S. The amplitude also varied greatly with tension.

Examination of the bimorph output with an oscilloscope showed that, especially at low frequencies, large harmonic content was present, unpredictable phase changes occurred and that there was a tendency to oscillate at double frequency.

6

These phenomena were explained by the fact that the wire was tending to oscillate in a "constant tension" mode, an increase in amplitude leading to an increase in tension and hence an increase in frequency of vibration. At higher tensions the effect, while still there, is minimised by the much smaller amplitude of oscillation.

If the amplitude of oscillation is made constant and small enough these effects can be reduced to insignificance. In practice, constant deflection amplitude is difficult to achieve as the output from the bimorph is frequency dependant but constant bimorph signal amplitude is readily accomplished by a relatively simple A.G.C. or compressor circuit and this has proved adequate.

For the sensor as used for balloon control little effort has been made at temperature compensation as only short term stability is required. There are however various ways in which the device is sensitive to temperature, these are :-

- (1) Linear expansion/contraction of the wire.
- (2) Differential expansion of wire/bellows.
- (3) Change in area of bellows, leading to change in sensitivity.

Item (1) as discussed previously is very small and is opposite in effect to (3). It would seem that a combined compensation is possible by compound fabrication of the beam. Given a symmetrical balance beam, if the related temperature coefficients are :- A = Bellows, B = Bellows half of the beam and C = Wire half of the beam, then $2A + B = C$ is the solution for compensation ignoring the wire coefficient. fig.7 shows an arrangement which should give a reasonable compensation with the distance X as a fine trim.

One item of importance here is the question of thermal mass. The wire has a much smaller mass than anything else so must be shielded from any draught.

The differential expansion factor should not ideally exist as we are measuring force on the wire. The bellows are made of small stiffness for this reason and it should automatically compensate. They do however have a finite

7

stiffness and a first order correction is accomplished by selection of materials i.e. brass bellows, steel upright supports to balance point and tungsten wire.

Power consumption of the device is low and due to the compression circuit there is little if any sensitivity to supply voltage. Using $13\frac{1}{2}$ volt mercury batteries the current consumption is around 10 milliamps.

Little attempt has been made to fully evaluate the performance of the sensor, especially with regard to long term stability, as this was not a critical factor in its intended application.

Used in conjunction with the logarithmic differentiator on a trial flight from Beaufort Park it succeeded in achieving the required control over the rate of descent of a stratospheric balloon which implies that it is inherently capable of measurement to rather better than 0.02 mb. Under these conditions the output is integrated over two periods of four seconds separated by a period related to absolute pressure at the balloon level.

Stability under constant tension is excellent and over an integration period of 10 sec appears to be rather better than 4 parts in 10^6 . Hysteresis, as predicted, seems to be very small but adequate measurement is difficult with available equipment and measurement procedures are complicated by expansion cooling of air in the test chamber.

Other Applications

Early versions of the "vibrotron" were unpopular with oceanographers because of the non linearity of output (the X/Y plot syndrome) and there was a great deal of largely unsuccessful effort made to overcome this. A modern weighing device using the principle makes life very complicated by unbalancing a pair of stretched wires and measuring the frequency difference. The mathematical approach via logic circuitry has not, so far as I am aware been attempted before and has proved surprisingly easy.

The circuit is illustrated in block (fig. 8) and is a digital squarer and scaler combined so that the final counter could give the output in any units directly.

With this in mind it would seem that the device might well be considered for other uses, for example, as a portable digital barometer, a pressure sensor for automatic weather stations and as a precision sensor for atmospheric soundings (i.e. Fog project).

The physics of the device are attractive in their simplicity, pressure to frequency direct and its output lends itself easily to telemetry. Once the temperature compensation problems have been thoroughly investigated (unnecessary for its present application) it would seem a reasonably robust, moderately priced, high precision device with wide possible application.

Squaring and Scaling Circuit

The frequency to be squared and scaled is f_2 .

From the block diagram (after reset):-

Time T_1 is derived from the oscillator (frequency f_1) and divider.

During this period f_2 is counted Up to give count 1.

At the end of time T_1 , f_2 is gated off and the counter is gated to count Down at frequency f_1 to give a time to count zero of T_2 .

During this second period f_2 is gated into decade counter to give count 2.

The decimal number here obtained is $f^2 \times K$ where $K = T_1/f_1$.

For the logic sequence in detail :-

Reset.

QN is low, G1 enabled, G3 disabled, G2 enabled.

Counter counts up at f_2 .

At time T_1 :-

QN goes high, M/S1 resets FF, enables G4, decade counter counts at f_2 ,

G1 disabled, G3 enabled, G2 enabled, counter counts down at f_1 .

Count reaches zero, M/S2 fires, as G5 is enabled this sets FF,

G4 disabled, count in decade counter is latched out by M/S2, M/S3 fires, resets counters.

Cycle repeats.

Some simple quantification :-

If the oscillator and first counter are taken as a 100 KHz crystal oscillator followed by a 20 stage binary counter. f_1 is taken from Q4 (at 6,250 Hz) and T_1 is defined by the state of Q20 at 5.24288 Sec. Then, given pressure is 1000.0 mb (represented by count of 10,000).

Using the formula $\text{Pressure} = \frac{f_2^2 \times 5.24288}{6250}$ or $f_2^2 = \frac{6250 \times 10000}{5.24288}$

We find $f_2 = 3452.67$ Hz.

This would be achieved by a 0.006" Tungsten wire of length around 6" stressed by a bellows of around 1.1" diameter.

Fig. 1.

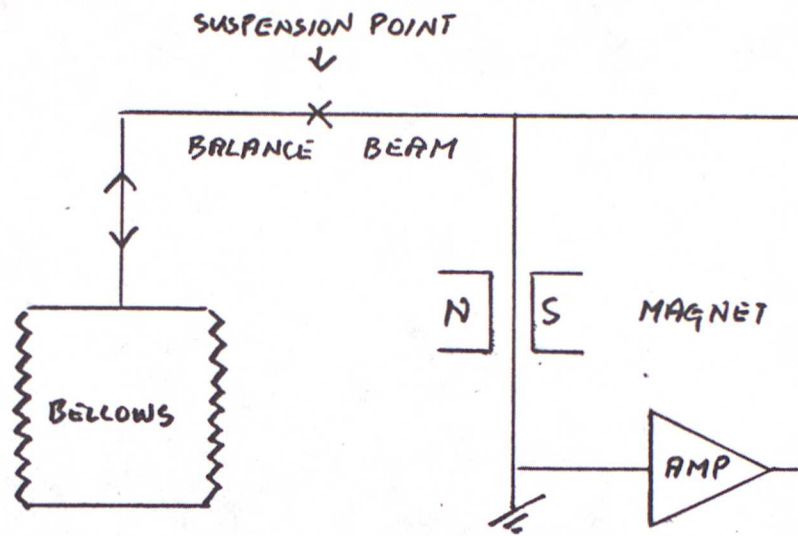
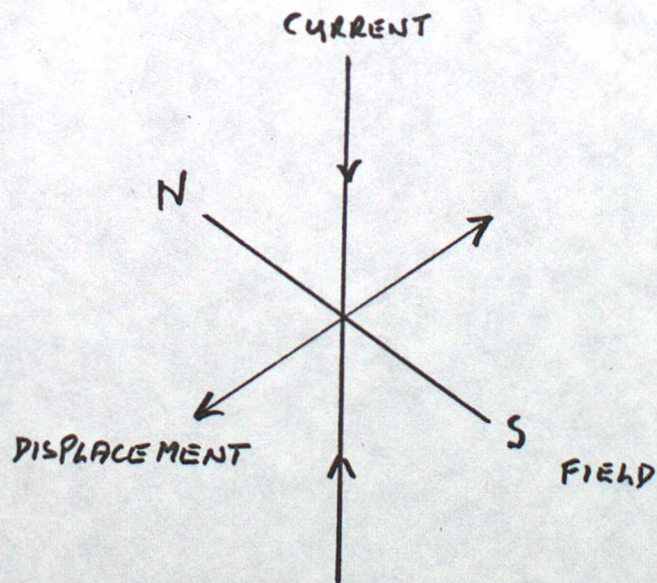
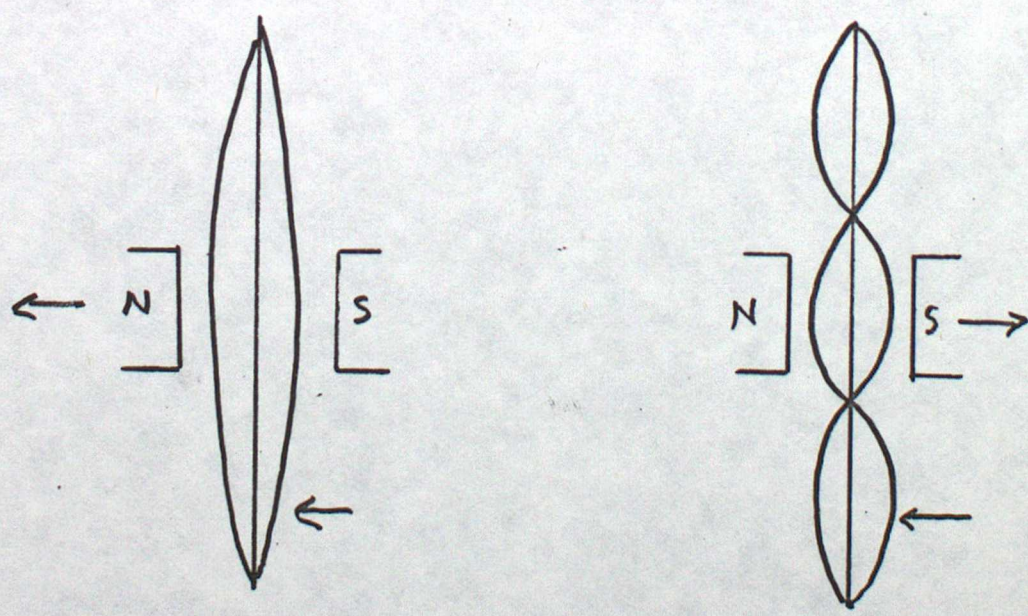
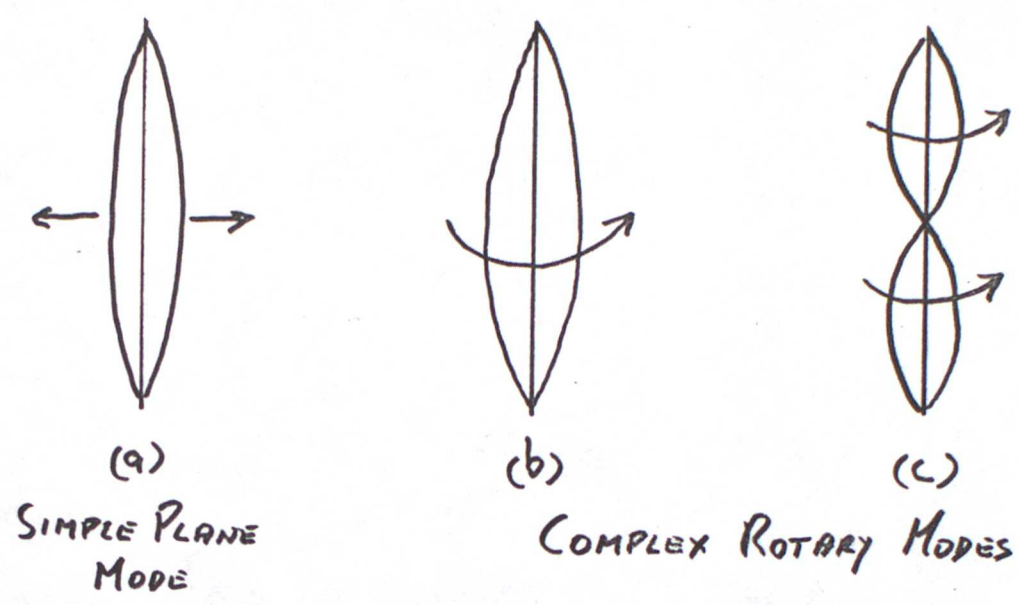


Fig. 2.





EFFECT OF PHASE REVERSAL OF DRIVE

Fig. 6.

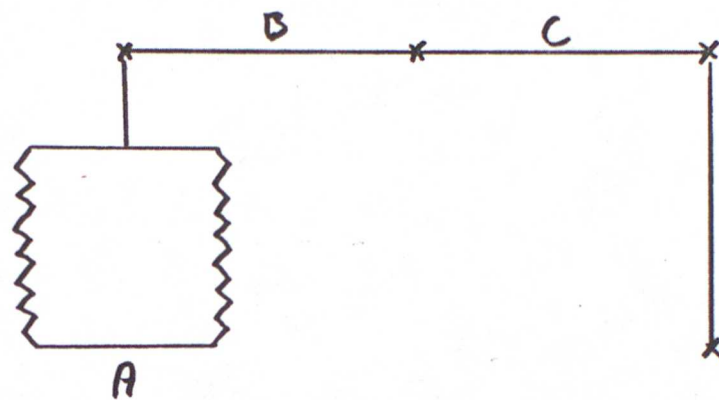
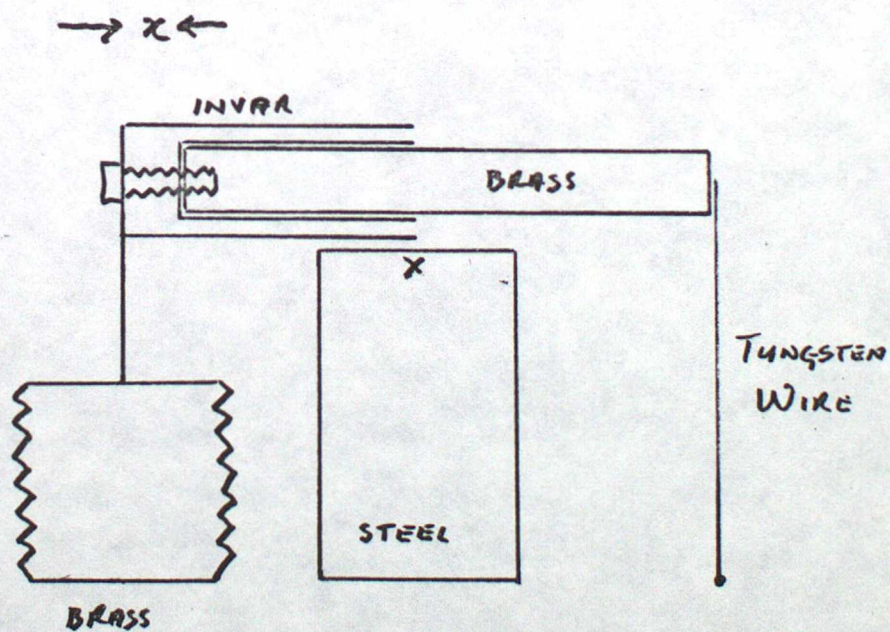


Fig. 7.



TEMPERATURE COMPENSATION
TECHNIQUE

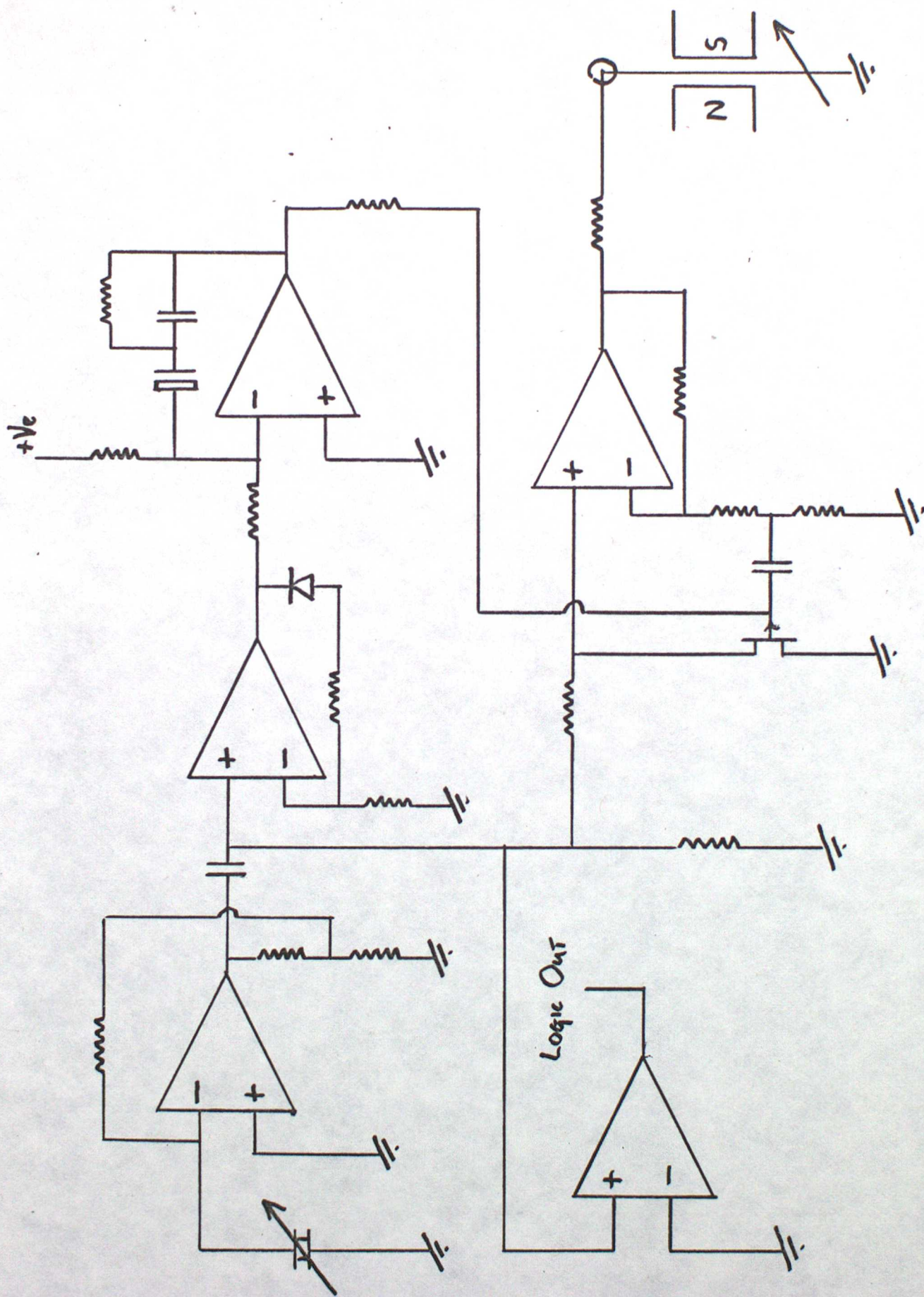
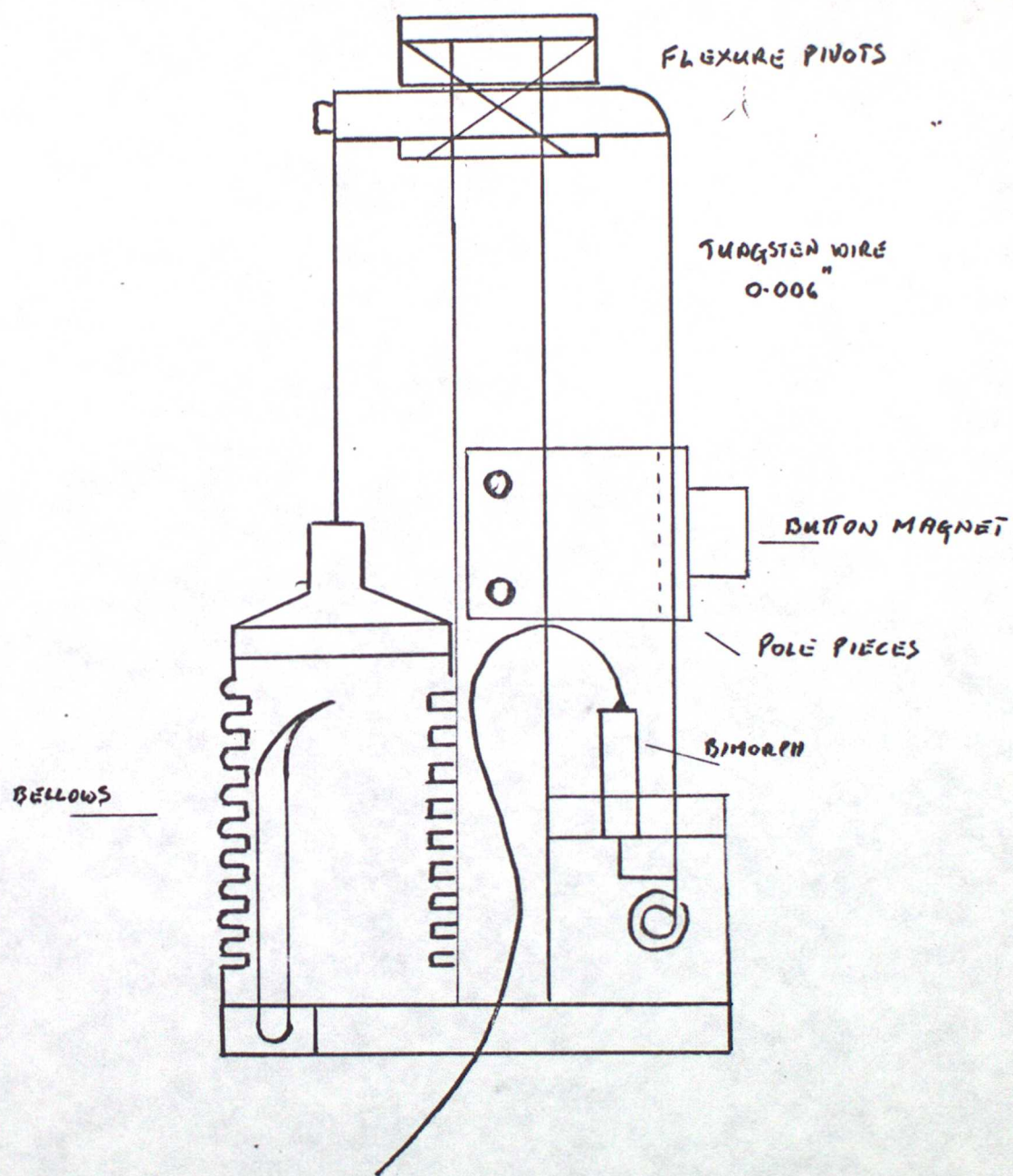


Fig 4.

A.G.C. Drive Circuitry for Vibratory Sensor



VIBRATORY SENSOR

Fig. 8
SQUARING & SCALING CIRCUIT

