The instrument was easy to operate and gave no trouble throughout the tests. The results were self-consistent and showed that at the centre of the water-cooled neck, with the air supply damper fully open, the gas temperatures varied between 1310 and 1390° C.

The instrument has also been used to measure temperature in town's gas and pulverized fuel flames. In the case of the former, difficulty was experienced in obtaining consistent pressure readings due to condensation of water from the hot gas on to the cold inner surface of the water-cooled probe. This difficulty was overcome by passing steam through the water-cooling passages. No difficulty with water condensation was experienced in any other tests so far carried out (due to the higher gas temperatures) but dust blockage of both orifice plates was experienced when testing in pulverized coal flames. The only solution for this was to clean the orifices as soon as periodic cold flow checks indicated that blockage had occurred (usually after two to three minutes' continuous use).

6. CONCLUSIONS

An instrument with a very high practical upper temperature limit has been developed and calibrated for use in the temperature range 200 to 1550° C, with an estimated accuracy of $\pm 5\%$. The temperature range is at present determined only by the upper limit of the calibrating unit.

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A sine wave generator for very low frequencies

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This report describes an experimental model of a simple form of generator of very low frequencies, using a cell containing an electrolyte in which two probes rotate continuously. As described it covers approximately the range 0·1 to 2·0 c/s with output levels variable between 2·5 and 60 V peak to peak.

A number of methods of generating very low frequencies have been described. Generally, they depend either upon the beating of two higher frequencies, one of which is variable, or upon the direct generation of the wanted frequencies from some form of variable resistance-capacitance oscillator. The first method is necessarily complex because of the very high frequency stability required of the beating oscillators. The second method, though simpler, requires extreme care in design to produce sinusoidal waveforms at frequencies of a cycle or less.

A third possible method might be the use of a sine or cosine type of potentiometer fed from a d.c. source. It could be arranged that continuous rotation of the potentiometer shaft produced an alternating voltage, the frequency of which was a function of shaft rotation speed. Suitable potentiometers are available but expensive, and at moderately-high rotation speeds their life expectancy would probably not be great. The same applies, from experience in this laboratory, to the use of linear potentiometers driven mechanically either by a swash plate or a Scotch yoke to produce a simple harmonic motion. With these devices, wear of moving contacts soon makes replacements necessary and unless much care is taken they may generate a considerable amount of noise.

The instrument to be described uses a variable-speed mechanical drive, with a cell containing an electrolyte, in which two probes are continuously rotated substituted for the sine potentiometer. A pair of slip-rings delivers the alternating voltage from the probes either direct to the load or through a d.c. amplifier as desired.

This method of generating a very low frequency has very probably been used before, although a search of appropriate abstracts for the past fifty years has not revealed any mention of it.

GENERAL DESCRIPTION

A photograph of the experimental model (Fig. 1) is almost self-explanatory. A motor (1/60 h.p. universal), the speed of which is controllable by means of a Variac, drives the slip-ring disk through a suitable reduction gear-train. On the slip-ring disk are fixed two probes, made of $\frac{1}{8}$ in. diameter silver-plated brass rod, each $2\frac{1}{4}$ in. long and spaced $1\frac{3}{16}$ in. between centres. The probe diameter chosen appears suitable for smoothing irregularities in electrolyte potential gradient.

A glass cell of square cross-section containing an electrolyte (tap water is quite satisfactory) is placed below the probes, and so elevated that the probes dip about $\frac{1}{8}$ in. into the electrolyte. Two 18 gauge copper sheet electrodes are fitted at opposite sides for the full width of the cell. Each is 2 in. wide and is immersed to a depth of about 2 in. A $4\frac{1}{2}$ V dry battery is connected to the copper electrodes.

Consider the probes so placed that their plane is first parallel to the electrodes, and then rotated continuously through 360°. Initially there is no potential difference between the electrodes. When rotation through 180° has taken place, there is again no potential difference between them. At the 90° position there will be a maximum potential difference between the probes, its amount depending on the geometry

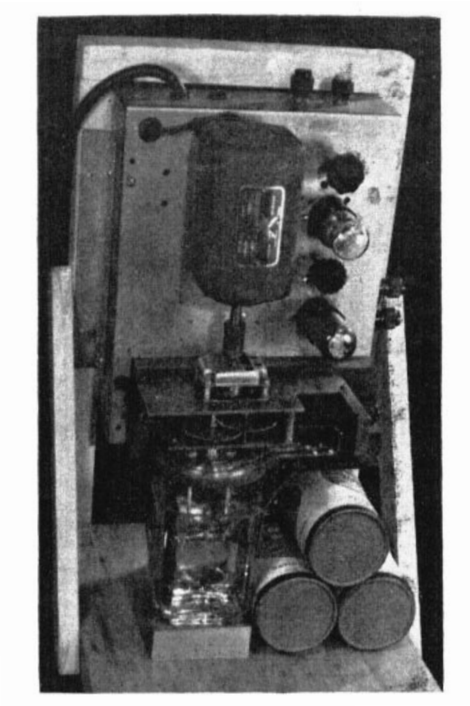


Fig. 1. Experimental model of generator

of the system. At the 270° position there will be another maximum of the same value as in the 90° position but opposite in sign. Hence continuous rotation causes an alternating voltage to appear across the probes, and in theory, with certain assumptions, that voltage will be sinusoidal.

The chief of these assumptions is that there is a uniform potential gradient, across the cell. Providing that the probe spacing is less than the width of the cell electrodes, and that the electrolyte itself is homogeneous (a condition that is aided by the stirring action of the rotating probes), this assumption is reasonable. Other variables, such as the eccentricity of the probes about their axis of rotation, the actual position of the probe assembly in relation to the electrodes, and the contact potential generated in the probe-electrolyte-electrode system, may displace the average level about which the alternating output voltage swings, but have no apparent effect on its waveform. Typical waveforms at speeds from 0·2 to 1 c/s taken on an Elektronik (by Honeywell–Brown Ltd.) recorder show very little departure from the pure sine wave.

For the purpose for which the instrument has so far been needed, it has been convenient to measure the generated frequency by either a stop-watch or by counting cycles from a recorder of known paper speed. With a suitable motor and reduction gear it would be possible to relate drive voltage applied to the motor directly to probe rotation speed. An a.c. voltmeter measuring the variable supply voltage could then be calibrated directly in cycles per second to a satisfactory repeatable accuracy.

The main shortcoming of the instrument is that it is not portable, the cell having to be drained and refilled if the instrument is moved any distance. In use, the cell gradually precipitates insoluble copper compounds, due to electrolysis, but the performance of the instrument is not affected.

AMPLIFIER AND OUTPUT CIRCUIT

With cell geometry as described the cell resistance is about 1000 Ω and the resistance between probes about 25 000 Ω. 2·5 V peak-to-peak are delivered to a high resistance load. For some purposes this was enough, but in one application about 10 V into a recording voltmeter was required. Hence some amplification was provided.

The circuit used is shown in Fig. 2. V_1 and V_2 are balanced cathode followers. They are fed from the rotating probes, across which is connected a bypass condenser C_1 to remove slip-ring noise. It has no effect on the low-frequency signal component. The cathode-followers drive a "cross-coupled" balanced stage, V_3 and V_4. Balance is reached by adjustment of RV_1 in the cathode chain. Across the anodes of these tubes appears about 60 V peak-to-peak into a 1 MΩ load. The ganged RV_2 are used as a variable series voltmeter resistance to the recording voltmeter. If a current instrument were to be used, appropriate cathode follower output could be added to deliver any current desired. The device under test would normally be inserted between probe output and amplifier input.

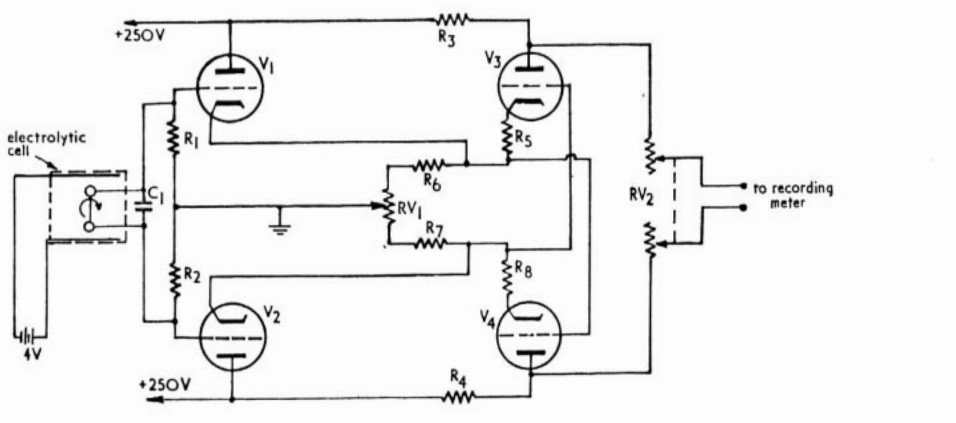
Fig. 2. Circuit of amplifier

R_1, R_2 = 470 kΩ
R_3, R_4 = 82 kΩ
R_5–R_8 = 1·5 kΩ

RV_1 = 1 kΩ wire wound
RV_2 = 50 kΩ wire wound

C_1 = 0·05 μF

V_1, V_2 = ½ 6SN7
V_3, V_4 = ½ 6SL7



CONCLUSION

This experimental instrument has been used successfully in measurements on high-pass filters to cut off below 0·5 c/s. Tests have indicated that its range should be extendible to 5 or 10 c/s before mechanical difficulties become serious.