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**MICROBAROGRAPH
INSTRUMENTATION**

by

H E Hansen

JUNE 1959

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The data shown in Figure 1 appeared first in the unclassified document, WT-303 by E. F. Cox, H. J. Plagge, and J. W. Reed, entitled "Damaging Air Shocks at Large Distances from Explosions - Operation Buster-Jangle," issued by AEC's Technical Information Service Extension, Oak Ridge, Tennessee.

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MICROBAROGRAPH INSTRUMENTATION

Introduction

The Atomic Energy Commission, in operating the Nevada Test Site some 70 miles north of Las Vegas, must insure public safety not only within the boundaries of the site but for many miles outside the test site proper. One of the far-reaching effects of nuclear detonations against which precautions must be taken is the blast effect which must be first predicted, then measured. It is in the prediction and measurement of blast effects at relatively great distances from the detonation point that microbarograph instrumentation finds particular importance. To explain Sandia Corporation techniques in microbarograph instrumentation, this discussion will be divided into three parts:

1. A short discussion of the principles of microbarograph measurement and of Sandia Corporation applications of the technique.
2. A short discussion of the technical requirements the instrumentation had to meet in performance.
3. A description, in some detail, of the equipment built by the Wiancko Engineering Company to meet Sandia Corporation requirements and specifications.

Principles and Applications

Under particular conditions of temperature and winds in the upper atmosphere, sound ducts are formed which can carry acoustic energy from blasts over relatively large distances. At certain locations, these sound ducts may cause focussing of acoustic energy back to the earth, but, at some intermediate locations, much smaller pressure effects may be present. An example of the effect of the so-called "ray paths" is illustrated by Figure 1, a reproduction of some actual microbarograph recordings taken after a high-explosive detonation at the Nevada Test Site. The graphs show that the pressure amplitude (52.4 microbars) recorded at Henderson, Nevada, 85 miles from the detonations, is nearly as large as the pressure amplitude (105 microbars) recorded at Indian Springs, only 40 miles away; yet, at Las Vegas, a point between these two locations, only 32 microbars were recorded.

Fig. 1 -- Microbarograph records of troposphere signals recorded southeast from 1.2-ton TNT shot, 0800 PST, November 13, 1951

Although ray paths and points of reinforcement can be fairly accurately calculated from meteorological data, there is no easy method of predicting within the necessary degree of accuracy what pressure amplitudes will be present. By providing pressure data which allow accurate prediction of pressure amplitudes, the microbarograph fills a special need.

The principle is quite simple. Microbarograph stations are established in the populated localities surrounding the test site. At H - 2 and H - 1 hours, 1500 pounds of high explosive is detonated near the nuclear zero point. Microbarograph pressure recordings are made at the various outlying stations where amplitude and time of arrival of the signal are read by the operator. These data are telephoned to the blast prediction unit at the test site and correlated to provide anticipated blast strengths throughout the area. On the basis of this prediction, and other considerations, a decision can be made about whether or not weather conditions are favorable for shooting the nuclear device.

Additional data of the structure of the atmosphere are provided by microbarograph when a dual station is used. A dual station consists of two microbarograph instruments sensing pressure on a radial line from the detonation and spaced at a distance of about 1 mile. The time of arrival of the signals at each transducer is accurately measured and provides a means for determining the angle of the impinging ray.

Technical Requirements

Like most instrumentation, it is necessary that this equipment be highly reliable, accurate, simple to operate, and reasonably portable. In addition, it was necessary to ask for several unique features not normally found in pressure or sound instrumentation equipment.

Since it is desirable to apply microbarograph measurements from locations only a few miles from the zero point to distances reaching several hundred miles, the dynamic pressure range of the instrument must be fairly large. Sandia Corporation specifications called for linear full-scale output recording from ± 4 microbars (60×10^{-6} psi) to $\pm 12,000$ microbars (0.18 psi), or a dynamic range of 3000:1.*

When making measurements on the higher sensitivities, i.e., only a few microbars, background noise from wind and man-made sources becomes troublesome. Fortunately, most of the acoustic energy at distances of several miles or more from high-yield explosions lies in a

* 180 microbars is equivalent to about a 1-foot change in altitude at sea level.

frequency band from 0 to 30 cycles per second, a fact which allowed us to solve the problem by specifying a low-pass filter.

Another problem from atmospheric noise still remained: How does one isolate against very small localized disturbances which are not representative of the character of the acoustic signal? This problem and the filter problem were nicely solved by a low-pass acoustical filter which was designed to sense pressure over a large area.

Sandia Corporation also demanded long-term stability (freedom from drift) both as a function of temperature and of normal atmospheric pressure changes. Since pressure noise signals sometimes occupied the frequency spectrum of interest, we also desired a variable band-pass filter within the 0-to-30-cycle-per-second band.

In order to easily record "time of arrival" differences in the signal, we desired the transducer to operate into cables varying in length from a few feet to a couple of miles, allowing us to locate recorders at the same point and supply them from a common timing generator.

To further complicate the problem, we did not wish to pressure calibrate the instrument each time it was used or each time the cable length was changed. But we did want a method of electrically standardizing and calibrating the system from end to end each time it was used. Therefore, a method of electrical calibration was specified.

To allow for errors in the prediction of pressure amplitudes, the output recording was made to consist of two traces with amplitudes set in a ratio of 4:1.

Through the joint efforts of Sandia Corporation and the Wiancko Engineering Company, these features were incorporated into the completed equipment.

Description of Equipment

Briefly, the microbarograph instrument is a rather conventional 1000-cycle carrier system using a variable reluctance transducer. Figure 2 is a block diagram of the system showing the main components involved. A reluctance bridge transducer fed by a 1-kc L-C carrier oscillator provides an unbalanced AC voltage proportional to pressure to an attenuator range circuit and balance circuit. In the balancing circuit, the in-phase and quadrature unbalance voltage from the transducer can be nulled with manually operated potentiometers. The signal is then amplified by a four-stage amplifier, and the signal is applied to a phase-sensitive demodulator. The demodulated signal passes through an adjustable band-pass filter to two DC driver amplifiers

Fig. 2 -- Microbarograph block diagram

adjusted to provide recording amplitudes in a ratio of 4:1 on a two-channel Brush recorder. Timing is supplied from an auxiliary generator and placed on the edge of the Brush recording with a side-marking pen.

The heart of the microbarograph instrument is really the transducer, operating on the principle similar to all Wiancko pressure transducers in that a twisted Bourdon tube is used to rotate an armature in a balanced magnetic bridge circuit.

Mechanically, the transducer consists of an enclosure with two cavities (see Figure 3). The lower cavity or front volume has a port through which the pressure signal is admitted. The upper cavity or back volume has two ports opening into the front volume. One port passes directly into the twisted Bourdon tube. The other, through a bleed plug, connects the front volume and back volume. The function of the bleed plug is to allow long-term equalization between the front and back volumes. Rate of pressure equalization through the bleed plug is approximately exponential and is nominally set for a time constant of about 20 seconds.

This equalization bleed plug between the front and back volumes represents, then, a high-pass acoustical filter with an adjustable cutoff frequency, usually adjusted for about 0.008 cps. The purpose of this characteristic is to prevent normal atmospheric pressure changes and internal pressure changes caused by temperature variations from affecting the zero signal output of the transducer.

Electrically, the transducer consists of a four-arm balanced bridge (Figure 4). Ignoring for the moment the permanent magnet, we see this is a standard four-arm variable reluctance bridge configuration. The armature, when rotated by the Bourdon tube, increases two of the magnetic gaps, at the same time decreasing the other two. The resulting change in inductance of the four windings unbalances the bridge and produces an output voltage at the signal output coupling transformer.

The most unique feature of this transducer is the electrical current calibration facility. This is illustrated in Figure 4 which shows a polarizing permanent magnet placed across the center of the E-cores. A steady magnetic bias is thus established through the magnetic circuit and allows the armature to be rotated like a motor if a DC current is passed through four bridge windings. We have here, then, the desired electrical calibration method mentioned earlier, which is independent of cable length since it is only necessary to insure that the current is always a predetermined value. A d'Arsonval meter serves the purpose of standardizing the current. The current calibration has been shown to be linear within 5 percent over the entire operating range. Field experience over many months, with frequent checking, has shown that the current calibration is reliable, i.e., repeatable, within about 2 percent.

Fig. 3 -- Microbarograph transducer

Fig. 4 -- Microbarograph current calibration

Acoustical filtering for rejection of high-frequency noise on the input to the transducer is provided by a "hose array" low-pass filter (Figure 5). The hose array consists of four 20-foot lengths of plastic garden hose laid out in the form of a plus sign with the transducer at the center. Five small orifices spaced at 4-foot intervals in each leg admit the pressure signals and, as sized in this application, provide a low-pass filter characteristic nearly flat to a cutoff frequency of 35 cycles per second. The large array layout provides coverage of a relatively large area and attenuates noise caused by small local disturbances. Also shown is the transducer with its tripod legs and shiny reflecting case.

Fig. 5 -- Sensing head and hose array assembled for operation - Bishop, California

A four-conductor shielded cable like Belden 8424 is used for excitation and signal transmission between the transducer and amplifier.

The input attenuator is a precision resistive voltage divider providing full-scale range selection of ± 4 , 12, 40, 120, 400, 1200, 4000, and 12,000 microbars. Ganged to the attenuator switch is a calibration current divider which provides a current of appropriate magnitude to produce a 75-percent transducer deflection on each of the ranges. Calibration steps can be applied at any time with a push-button switch on the front panel.

An auxiliary input to the calibration circuit allows a low-frequency oscillator to be used to provide a current input and is useful for obtaining dynamic and transient response information on the instrument.

This unique current calibration method of standardizing the system gain is one of the most interesting and useful design features of the instrument. It allows the operator to standardize easily his gain on any range by merely setting the calibration current and operating a push-button switch.

A four-stage R-C coupled amplifier (see Figure 2) provides the necessary signal amplification for driving the demodulator and gives a linear output over a dynamic range of ± 50 volts.

A phase-sensitive gated demodulator has a comparable linear operating range of ± 50 volts, about ten times that needed to accommodate normal full-scale signals. This large dynamic range is desirable to prevent small system drifts from causing nonlinearity and to provide the necessary range to accommodate the recorder having a sensitivity of one fourth.

Following the demodulator is a step variable R-C band-pass filter. Low cutoff frequencies may be selected by a rotary switch at DC, 0.01, 0.03, 0.1, and 0.3 cycles per second. High cutoff frequencies may be independently selected by another rotary switch at 1, 3, 10, and 30 cycles per second. Gain compensation in the amplifier is automatically accomplished by switching feedback parameters and corrects for the difference in signal level introduced by the insertion loss of the filter combination selected.

Having the facility to change the band-pass characteristic of the system is frequently very handy in reducing noise when operating at high sensitivities.

The recorder driver amplifiers are conventional signal-ended direct-coupled amplifier circuits with the addition of peak-clipping diodes. Damage to the recorder pens is prevented by the clippers when large transients are present.

Figure 6 shows the instrument front panel which includes resistive and reactive balance controls, an over-all gain control, balance meter, filter selector switches, electrical calibration and zero buttons, calibration current and carrier level adjustments, and a meter for indicating carrier and calibration current level.

The simplicity of operation of the instrument is evidenced by the fact that technically untrained personnel have learned to operate it after just a few days of instruction.

Conclusion

Since 1953, Sandia Corporation has used this particular piece of equipment for every nuclear test operation. In that time, only minor maintenance and repair have been necessary. By providing accurate data, this equipment has indeed fulfilled its function of assuring public safety during the operation of the Nevada Test Site by the Atomic Energy Commission.

Fig. 6 -- Microbarograph instrumentation panel