Basic Instrumentation at the National Bureau of Standards

A PROGRAM of research and development in basic instrumentation is now in its fourth year at the National Bureau of Standards. Under the general direction of W. A. Wildhack, Chief of the NBS Office of Basic Instrumentation, new applications of physical principles are being evaluated and applied to problems in measurement and control. Theoretical analyses are also conducted in various phases of instrumentation, and critical surveys are made of available instruments and techniques for types of measurement that are becoming increasingly important.

The NBS Office of Basic Instrumentation was established in 1950 to serve as a research, reference, and consultation center on problems of instrumentation for the laboratories of government and industry. Its program is sponsored by the Office of Naval Research, the Air Research and Development Command, the Atomic Energy Commission, and the National Bureau of Standards. While this program constitutes only a relatively small part of NBS activities, it represents an effort to utilize the Bureau's facilities and experience in the field of physical measurements to advance those techniques of measurement and control that are fundamental to progress in science and industrial technology.

Improved instruments for measuring basic physical magnitudes are vital to advances in the physical sciences and their applications (*1–3*), yet until recently the problem of designing instruments to measure different quantities and for use under different conditions has been largely left to the individual scientist or engineer working in his particular technical field. However, it is coming to be more and more widely recognized that the problems met with in designing various kinds of scientific instruments have much in common and that the designer of an instrument for a specific purpose can often benefit from the experience gained by others with instruments built for quite unrelated purposes (*4*). In an effort to realize the advantages that would accrue from coordinated planning of research on instrumentation as a science in itself, the NBS Office of Basic Instrumentation was established. Under such a program, it has been possible to take advantage of ideas and developments originating in various technical fields that have a bearing on basic instrumentation problems.

The technical work of the Office of Basic Instrumentation has two principal objectives: (*a*) systematic analysis of available methods and devices in terms of their performance and characteristics and (*b*) research on new applications of principles and materials leading to the development of instruments and techniques not now available. This program is carried out largely through the assignment of instrumentation research projects to those NBS laboratories that are best qualified to conduct research in the particular field of science involved (*5*). However, the Office of Basic Instrumentation also maintains a small laboratory staff of its own for investigation of special problems and a group of specialists in instrumentation literature who are developing a reference and consultation service to aid in the solution of instrumentation problems.

The various projects included in the technical program may be classified into four groups:

1) Critical surveys of available instruments or techniques for certain types of measurement that are taking on increased importance.

2) Projects for the theoretical or experimental evaluation of new applications of physical principles to general problems in measurement and control. Normally such projects are limited to a basic exploration of probable fruitful applications and do not involve development of specific instruments incorporating such applications.

3) Projects for the new application of physical principles to specific problems in measurement and control.

4) Projects for theoretical analysis and development in various fields of measurement, control, or handling of measurement data.

In the earlier phases of the program, experimental projects of the types described under (2) and (3) predominated, largely because technical personnel particularly suited for a number of such projects were available. However, as the program proceeded, it has been possible to place additional emphasis on projects under (1) and (4). In particular, survey projects have been initiated in a number of important areas.

Surveys

The critical surveys of various general types of instruments are designed to assist the engineer or scientist in making the proper selection of existing types of instruments for new applications as they arise or to aid him in combining various elements of known characteristics in the design of new instruments. Such surveys also provide the information needed for adequate planning of more specific instrumentation projects. Surveys of this kind now in progress include studies of millimicrosecond oscillography, dynamic pressure instrumentation, strain-gage recorders, voltage-sensitive devices, and analog-to-digital converters.

Large fluctuations in fluid pressure, often occurring at high frequencies, present an important problem in the design and operation of jet aircraft, rockets, and chemical plants. Recent needs, particularly in aeronautic and ordnance research, for making dynamic fluid-pressure measurements have indicated the practical necessity of a survey in this field. It is believed that an up-to-date compilation of significant techniques will be of great value to all workers faced with such problems. Thus far a bibliography of about 250 books, articles, and reports of various government research laboratories, covering the period from 1920 to the present, has been assembled, and a broad outline has been prepared to guide an investigation of the literature. The present bibliography is to be extended, and individual articles are to be reviewed and summarized. The manufacturers' literature will also be reviewed, and some attempt will be made to evaluate instrument performance where data are available.

The survey of millimicrosecond oscillography has also progressed. Recent developments in radar, television, atomic physics, telemetering, and other fields have greatly increased the need for oscillographic measurements in the time range below one microsecond. As a result, newer and faster oscillographs are being developed. Such instruments will also find applications in the study of electrical breakdown under steeply rising voltage surges—a subject of growing importance in insulation testing. A survey in this field is expected to be useful not only in the planning of new research but also for guidance in instrumentation problems concerned with the recording of high-speed transient voltages.

Although analog-to-digital converters are used in a number of different applications and new types are being developed to meet new situations, the development and use of such devices has been hampered by the lack of a comprehensive picture of the requirements to be met and the techniques presently used to meet them. In an effort to bring widely scattered information on this subject together, data have been collected on analog-to-digital converters manufactured by commercial companies and on those now being developed by these companies and by government agencies.

The survey of strain recorders, recently undertaken, has as its object the gathering of technical information that will aid in the selection of equipment for producing autographic stress-strain records of tensile tests. The use of recorders for this purpose has become standard practice in most materials testing laboratories. However, the recorders are supplied by manufacturers in a variety of forms, and there is little in the open literature to guide the user in the selection of equipment. There is even less information regarding the accuracy of recorders and strain gages. The results of this survey will be based on laboratory studies at NBS as well as on information obtained from other sources.

Specific Problems

Laboratory studies of more specific problems in instrumentation have resulted in a number of developments having broad potentialities for measurement or control. For example, a method[1] was developed which uses heavy water to determine the total water content of biological tissues, proteins, inorganic crystals, and other materials. Based on a spectroscopic measurement of the ratio of ordinary to heavy water in a solution containing the sample, the isotopic method is outstanding in the rapidity and convenience with which it can be applied to a large number of samples.

[1] Isotopic method determines water content, *NBS Tech. News Bull.*, **36**, 145 (October, 1952).

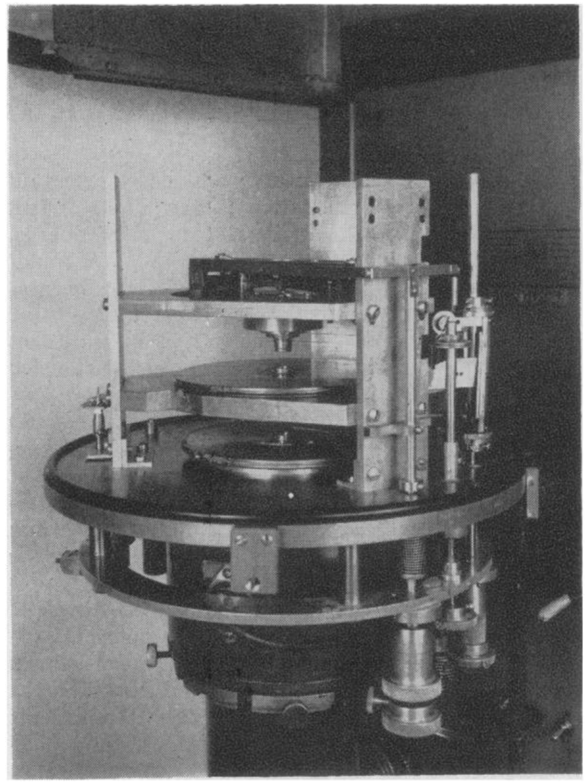

Fig. 1. Internal mechanisms of the NBS electron-beam interferometer. The interferometer employs diffraction from an extremely thin crystal as a means for splitting and recombining an electron beam and uses an electron optical system for viewing the resulting interference phenomena. Three crystals are mounted in an evacuated chamber that replaces the object chamber of an electron microscope. Each of three crystals are placed on mounts that may be rotated about the optical axis. The mount of the first crystal (top disk) may also be translated. The spacing between each crystal is 3.48 cm. Copper crystals approximately 100 A thick and about 3 mm in diameter are enclosed in small capsules that are placed in the center of the disk-like mounts. The controls for the crystal motion are brought to the outside of the chamber through vacuum-tight seals.

In another project of this kind, research on the wave properties of electrons has resulted in the development of an interferometer[2] that utilizes electron beams to produce interference fringes in much the same way as conventional optical interferometers use light beams. The NBS electron interferometer (Fig. 1) greatly extends the range of light interferometers used in the direct measurement of length. The instrument also constitutes an extremely sensitive device for measuring gradients of magnetic and electrostatic fields, analogous to refractive indices in optical interferometry,

[2] Electron-beam interferometer, *NBS Tech. News Bull.*, **37**, 101 (July, 1953); Electron interferometer, by L. Marton, *Phys. Rev.*, **85**, 1057 (1952).

and provides a means for obtaining additional information on the wave nature of the electron. Other suggested applications of the method include studies of the energy levels in solids and an absolute determination of Planck's constant.

Spurious electrical signals, or "noise voltages," present a problem in many types of instrumentation work where cables are subjected to mechanical shock and vibration. They interfere with measurements of pressure in underwater explosion and air-blast research and with determination of acceleration in shock and vibration studies. They also adversely affect the performance of crystal-type microphones, hearing aids, and phonograph pickups, and of many other high-impedance devices in the fields of communication, measurement, and control. The mechanism of the noise generation was not generally understood and was often assumed to be somehow related to piezoelectric or converse electrostrictive effects, changes in the electrical constants of the cable, or separation of electrical charges by friction. Last year a detailed theoretical explanation was formulated for the generation of the spurious signals, and a low-noise instrument cable[3] was developed.

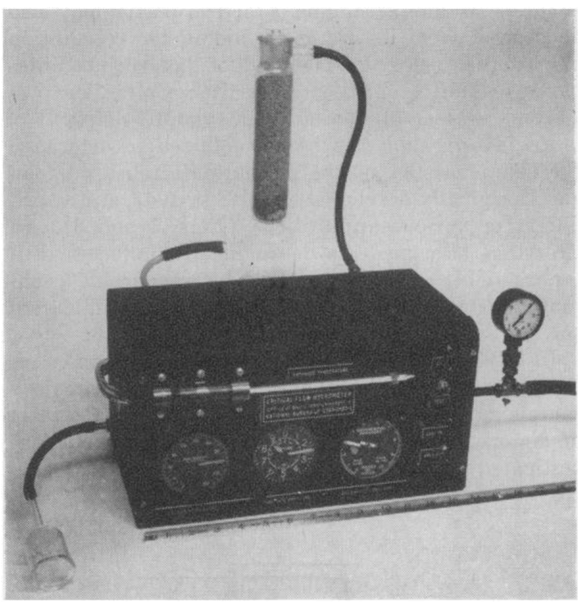

FIG. 2. Critical flow hygrometer developed by the NBS Office of Basic Instrumentation. The device is based on the principles of gas flow at sonic velocity through orifices.

In connection with a program aimed at extending the range and accuracy of dynamic mechanical measurements, the NBS Office of Basic Instrumentation in 1951 developed a miniature piezoelectric accelerometer[4] for direct measurement of high-frequency vibrations. The device, which employed a barium titanate

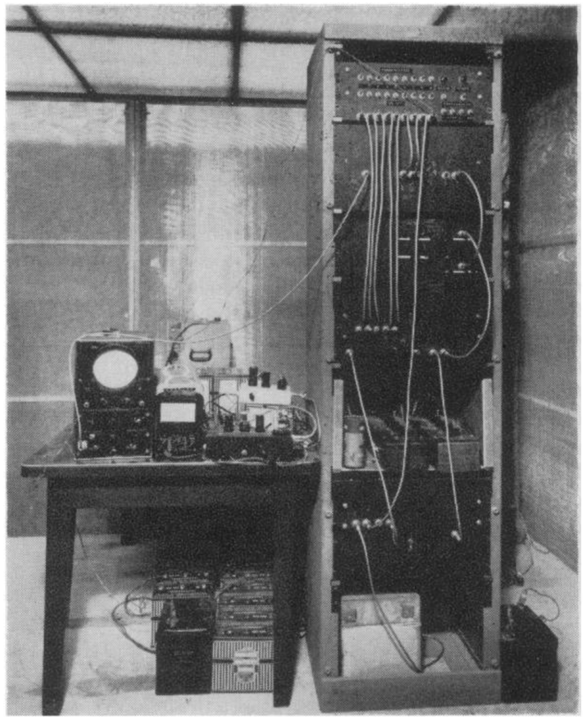

FIG. 3. The thermal noise thermometer, an instrument which determines temperature from the thermally generated electrical disturbance in an electronic circuit. Originally conceived and constructed at the University of Chicago, the noise thermometer has been redesigned by the Bureau in connection with its program in basic instrumentation. Amplifiers for the current from the temperature-sensitive element are at right. At left are a monitoring oscilloscope and an integrating circuit.

crystal as the compressive element, was extremely small but in many ways superior to other instruments used to measure mechanical vibration and shock. Further investigations of the barium titanate accelerometer, largely concerned with design characteristics and calibration methods, have continued. In the course of this work a model has been developed having exceptionally wide ranges of acceleration and frequency response (50,000 *g*, 100,000 cps).

Research and development work on applications of pneumatic principles has resulted in a series or family of new instruments[5] based on gas flow at sonic velocity through nozzles. Utilization of these principles promises to provide improved instruments for the measurement of pressure, temperature, rate of flow, humidity, gas composition, mechanical displacement, and other quantities. A humidity measurement instrument has now been completed, providing a background of information that should be of value in the development of other instruments using the sonic flow principle (Fig. 2).

Other investigations of this kind that have been undertaken deal with such topics as the thermal noise thermometer, an electronic coating thickness gage, a carbon dioxide hypsometer, strain and displacement in-

[3] Noise-free instrument cable, *NBS Tech. News Bull.*, **36**, 37 (March, 1952).

[4] Miniature piezoelectric accelerometer, *NBS Tech. News Bull.*, **35**, 141 (October, 1951) ; A ceramic accelerometer of wide frequency range, by Lawrence T. Fleming, *Instruments*, **24**, 105 (1951).

[5] A versatile pneumatic instrument based on critical flow, by W. A. Wildhack, *Rev. Sci. Inst.*, **21**, 251 (1950).

struments, an ultrasonic velocimeter, feedback around image scanning systems, a phase sampling telemeter, the mutual inductance transducer, measurement of humidity by spectroscopic methods and microwave techniques, neutron spectrometer evaluation, and nucleonic instrumentation utilizing memory devices.

The carbon dioxide hypsometer represents an attempt to utilize the temperature of subliming solid carbon dioxide in equilibrium with its vapor at ambient pressure as a measure of pressure in upper air research. Several experimental models of this device have now been constructed and tested at pressures corresponding to altitudes up to 105,000 feet. The noise thermometer project was designed to evaluate the capabilities of the noise thermometer (Fig. 3), originally developed at the University of Chicago, as an instrument for measuring temperatures on the thermodynamic scale and to investigate the suitability of the device for other temperature measurement and control applications. The ultrasonic velocimeter is expected to provide a simple, accurate method for measuring the speed of sound in liquids. A model of the device is now being used by the Navy to measure the speed of sound in water at various depths. The electronic thickness gage is designed to nondestructively measure the thickness of metallic coatings which differ from the basis metal in electrical resistivity or in magnetic properties. The gage is capable of working with nonmagnetic metals in applications such as the measurement of the thickness of silver on brass. The phase sampling telemeter, which utilizes a commutator-type sampling device, has been proposed as a system that may offer improvements over present telemetering systems for certain applications in accuracy, reliability, complexity, weight and size of components, and power requirements. The project on strain and displacement instruments involves work on high-range and high-temperature types of strain gages as well as the design and construction of improved models of the Ramberg vacuum tube accelerometer,[6] originally developed by NBS in 1946 for acceleration measurements in aeronautical work (Fig. 4).

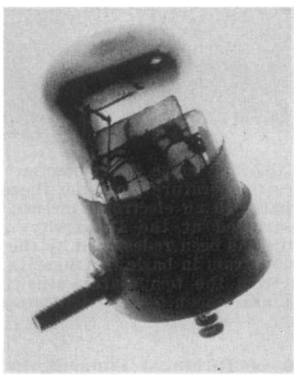

FIG. 4. The Ramberg vacuum tube accelerometer is essentially a double diode with elastically supported plates on either side of the common cathode.

[6] The improved Ramberg vacuum tube accelerometer, *NBS Tech. News Bull.*, **34**, 180 (December, 1950).

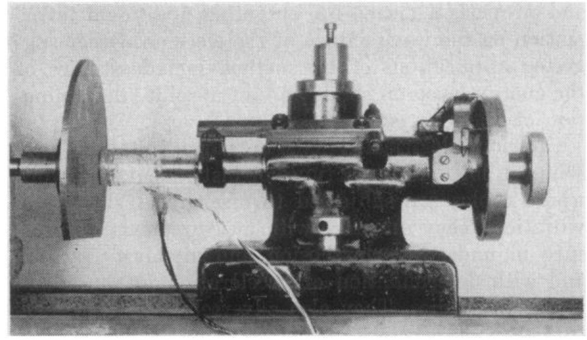

FIG. 5. Model of the mutual-inductance micrometer, originally developed by the NBS. The device employs two coils (left), a primary and a secondary. Alternating current fed into the primary induces current into the secondary, and the amount of this current varies with the distance of the secondary from a conductive shield. The thickness of a nonconductive medium between the secondary coil and a metal surface can thus be measured.

The work on image scanning systems is a study of the application of two-dimensional linear and nonlinear feedback in optical-electronic systems using cathode-ray tubes. Contributions to research may result from solutions of nonlinear partial differential equations by this technique. Practical results may also be derived from its use as an aid in the recognition of patterns, such as the matching of fingerprints, automatic reading of printed or written matter, or possibly in weather prediction from synoptic maps.

An investigation has been conducted to determine the characteristics of the mutual-inductance micrometer,[7] originally developed by NBS in 1947, as a transducer for various applications (Figs. 5 and 6). An effort has been made to determine the influence of a large number of factors on the performance of a mutual-inductance transducer so that the optimum design for any specific use can readily be chosen.

In 1950 NBS developed a recording microwave refractometer[8] of high sensitivity that can continuously sample and record the dielectric constant of a stream of air or other gas. This instrument is now being investigated to determine its potentialities for use as a

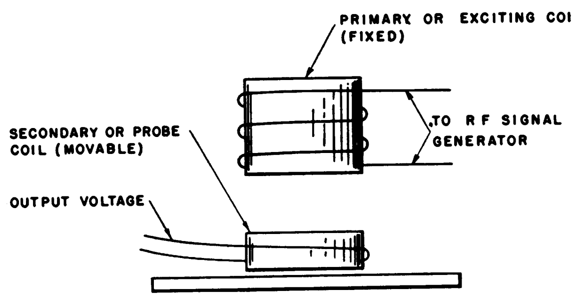

FIG. 6. Schematic diagram illustrating the principle of the mutual-inductance micrometer shown in Fig. 5. An investigation to determine the characteristics of this device as a transducer for various applications is being carried out as part of the NBS Program in Basic Instrumentation.

[7] Electronic micrometer, *NBS Tech. News Bull.*, **34**, 137 (October, 1950).

[8] Recording microwave refractometer, *NBS Tech. News Bull.*, **34**, 45 (April, 1950).

humidity standard. In another project, the Office of Basic Instrumentation is studying the possibility of utilizing the hydrogen excitation spectrum for absolute humidity measurements at low temperatures.

Because the neutron has no electric charge, the measurement of neutron energies is a problem quite different from that of electron, proton, or alpha-particle energy measurements. Thus far, methods that have been employed for this purpose have been quite varied in principle. The work on neutron spectrometer evaluation will involve a summary of characteristics of neutron spectrometers now in existence and an evaluation of proposed designs for new types. The project on nucleonic instrumentation will be concerned with the development of fast memory tube-type pulse-height analyzers for nuclear research. It will also attempt to extend the use of memory tubes to other types of nuclear instrumentation. Another project in this field which is now being planned will include the construction and absolute calibration of a standard slow-neutron flux free of gamma rays and the development of instruments and techniques for intercomparison of unknown fluxes with this standard flux.

The projects described above, while not a complete listing, are typical and serve to indicate the scope of the work carried on by the NBS Office of Basic Instrumentation. Continual modification of the program and its objectives may be expected as the science of instrumentation develops and new instruments and measurement techniques become available.

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4. ———. *Ibid.,* **114**, 3 (1951).
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The Basis for a Science of Instrumentology[1]

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CHOICE OF WORDS can sometimes lead to confusion and misunderstanding. Under a title involving the word "instrumentology," I might well be expected not only to discuss instrumentology but even to know what the word means, particularly as contrasted with the more widely used term "instrumentation." Being unable to live up to these expectations, I shall make little use of either word, assuming only that in dealing with instrumentology it is proper to stay close to the concept of quantitative measurement.

We all do things we do not fully understand. Not every housewife who bakes a cake, even a highly successful cake, is well versed in organic chemistry and kinetic theory of gases. Nor do organic chemists themselves always understand *their* concoctions. Man has been measuring and controlling for a long time, and it is no derogatory reflection whatever on the usefulness of this activity to say that we still do not understand it as fully as we wish. Many good men have contributed toward a better general understanding of measurement and control—men such M. F. Behar (*1*), who has been closely identified with the applications, men who combine teaching and engineering, as does C. S. Draper (*2*), and men like the theoretical physicists Leo Szilard (*3*), John von Neumann (*4*), and David Bohm (*5*). In continuing to show today preoccupation with the task of reaching a better grasp of the fundamentals of the field, I wish to make forthright acknowledgment, first to those who by their infinitely varied, down-to-earth practical activities make the field, and make it the fascinating subject for speculation which it is, and second, to those who have contributed to such broader, more theoretical insight as we already have.

Measurement is an activity in which certain devices, instruments, are used. Let us look first at some of the terms reflecting (for example, in the Help Wanted columns) activities more or less closely related to measurement and control. Such activities are displayed in Table 1 in relation to the information concept. For the moment, at least, the words "information" and "thought" are used with the understanding that everybody knows their meanings but nobody can express these meanings in definitions. Since this has always been done with the word "time," we have in a double sense a time-honored precedent.

These activities are carried out both by human beings and by inanimate, or robot, devices. This has been emphasized by putting in the left-hand column terms characteristically applied to robot action and in the right-hand column terms characteristic of the human analogue. This kind of comparison between the human and robot analogues is of definite value in promoting understanding of both.

Now the two words which occur throughout this table are "information" and "thought." The close relation between the two can be illustrated by asking ourselves such a question as this: "Do we generate information when we get a new thought?" The arrangement in the table implies some difference between thought and information, since information is

[1] Presented at Gordon Research Conference, July 27, 1953.