ute. In this example, low-level counting would make possible a factor of 10^{-4} or better in the necessary residual radioactivity.

One of the questions concerning the realization of the potential future of large-scale industrial tracers is the danger of the residual radioactivity to the consumer. The natural tracer experiments with tritium and carbon-14 indicate the answer. Consider the use of tritium as a tracer in the petroleum industry—for example, in the tagging of oil for identification of leaks from underground storage. Even if a world output of 7×10^9 barrels of oil per year were tagged at a measurable level of 10^{-6} curie per barrel, the steady-state increase in the world inventory of tritium would be less than 1 percent. Even the maximum transients in water would be less than 0.5 percent of the maximum permissible amount (*52*) of tritium in water. In the case of carbon-14, the entire world output of sugar could be regularly tagged at the easily measurable level of 10^{-11} curie per gram of carbon with a corresponding maximum increase of only 0.1 percent in the world inventory of radiocarbon. It is clear that with reasonable care and modern instrumentation, safe large-scale tracer operations can be realized.

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Electronics for Measuring Human Motions

Jay Goldman and Gerald Nadler

Measuring the performance of people at various work activities has been an essential task in many fields, both academic and industrial. Physiology, psychology, and physical education are some of the academic endeavors requiring a measure of output or performance of persons for purposes of studying relationships to various factors. For example, the physiologist wants to measure the direct result of some muscular activity that he may be studying, in order to correlate the two results. The psychologist in biomechanics wants to measure the output of a subject when he is trying to design man-machine relationships. The physical educationist should be able to make a complete measurement of every part of a tennis or golf swing.

Although industrial engineering is both an industrial function and an academic pursuit, most of the research problems stem in some way from problems in the industrial situation. A review of some of these problems will point out the essential necessity for measuring operator performance in industry and how the lack of suitable measurements has led to the development of a device which should help all activities concerned with human performance.

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Background of Work Measurement

In today's highly competitive economy, a progressive enterprise must attempt to perform its operating function in the most effective manner possible. Work-measurement techniques (of which time study is one) are among the most useful tools available to modern managements. Work measurement establishes the standard time required to perform jobs. The success or failure of enterprises involving literally billions of dollars rests on bases that consist, to some major extent, of these standard times.

Both management and labor have a great stake in work-measurement techniques. Work measurement affects all types of people, presidents and workers, supervisors and union stewards. In this sense, the utilization of work measurement is dependent on human beings as well as on its projected technical application. If there are any inaccuracies or inconsistencies in the strictly technical sense, there is a large area for the development of friction between the parties (usually management) applying and using the techniques and the parties (usually workers and unions) to which the techniques are applied. Such friction can be a major cause of costly strikes, for example, the recent Westinghouse situation.

More labor-management cooperation can be expected as a natural result of management's awareness of general problems in human relations and, probably just as important, of the developments of technical research in the field of work measurement. More cooperation can be expected between any parties when the basis for their mutual understanding is broader. This is the purpose behind much work-measurement research. The lack of accurate work-measurement theories, information, and measuring devices on which to base many of the decisions needed in the labor-management area has caused much of the difficulty that exists between labor and management.

Management itself needs the time standard to form the base upon which many operating procedures are built. Such procedures include balancing work (and production lines), determining equipment requirements and manpower requirements, planning production processes and layouts, planning costs of new and revised products, controlling production, and controlling the costs of production. Of course, good wage-incentive programs require good work measurement. This list can be expanded many times and is limited only by the imagination and ingenuity of the organization.

Although some of these functions can be accomplished without work measurement, they are not usually performed as satisfactorily by other means alone as with the aid of these techniques, even though work measurement involves some errors. An end-result is only as valid as the base from which it is obtained. A high degree of accuracy is necessary for all work-measurement situations, but techniques should provide a way to make these measurements as accurate as possible, and they should also provide a base reference point for the estimation of errors.

Many factors affect the performance of a human being on the job, but the most important factors are centered in the human being himself. Putting aside other factors, it is readily apparent that it is now impossible to measure all the human causal factors affecting the performance of a person. The measurements, therefore, are made of the effects of these causes. The speed of motion is one of these effects, and it is the one usually measured. To measure accurately speed of motion, the values of velocity, acceleration, deceleration, position, distance, and direction for all possible motions the body members can perform must be obtained. No measuring device has been available for making all these measurements.

In designing a new device for making these measurements, certain new factors had to be considered. For example, the measurements must be three-dimensional; attachment to the body member must be small and light; devices must operate under all factory conditions; the range of velocities measured may be small (0 to 10 feet per second), while the range of acceleration and deceleration may be large; and measurement systems must be designed to give immediate results.

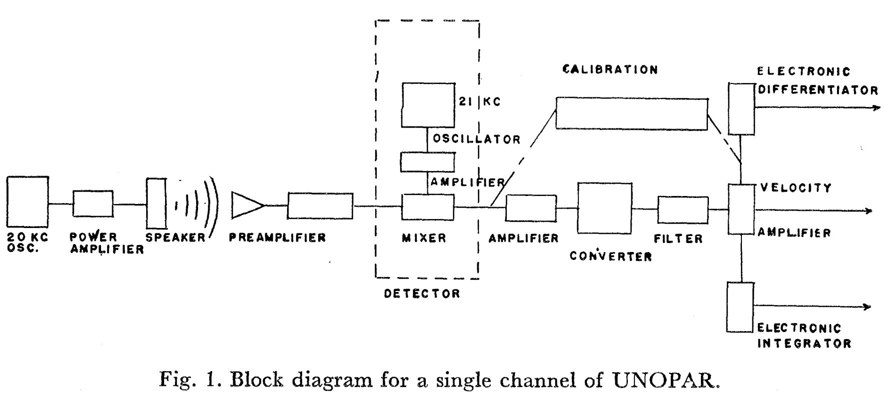

Fig. 1. Block diagram for a single channel of UNOPAR.

Development of Work-Measurement Device

After careful consideration of all possible measuring techniques, we decided that the Doppler effect with sound as the radiation medium presented the fewest formidable obstacles for successful development of a work-measurement device. The device designed is called a Universal Operator Performance Analyzer (UNOPAR). Its operating frequency of 20,000 cycles per second is just above the threshold of hearing at normal levels of intensity. This frequency helped overcome the interference problem from other noises within the factory. The sound-emitting source must be attached to a body member, but eventually the size of this source will be no longer than a wrist watch, or even a ring on a finger.

Three microphones, oriented in three planes with the directional axis of each perpendicular to the directional axis of the others measure motions in the three planes. Each microphone receives its component portion of the sound waves projected from the speaker on the body member moving toward or away from the microphone. This system provides a variable axis of reference, since the three planes can be rotated. This permits flexibility to circumvent obstacles to the path of transmission and to permit use of overhead space in industrial situations.

Because of the Doppler effect, a transmitting source of sound that is in motion relative to a stationary receiver provides an apparent frequency of sound at the receiver that varies directly with the velocity of the source. Motion toward the stationary receiver will increase the frequency received, and motions away from the stationary receiver will decrease the frequency received.

According to the Doppler effect, only one-plane motions toward or away from any receiver should be registered as true speaker motion. This presents a practical operating problem, for the receiver is a fixed point of reference, and the speaker is a variable one. When the speaker is moving in a path perpendicular to the microphone, the direct distance between the speaker and the microphone varies. The greater the variability of this distance, the greater the error. For practical application, the motion of the speaker is assumed to be confined within a 1-yard cube, and the microphones are placed 10 feet away from the center of this cube, so that the maximum possible error will not exceed 1 percent of the true motion.

Operating Procedure

The basic operating procedure of UNOPAR begins with the generation of the operating frequency of 20,000 cycles per second. As is indicated in the block diagram (Fig. 1), this 20-kilocycle signal is sent to a power amplifier and then to the speaker. Most of the limited research work performed to date has been done by moving a speaker rather than by attaching a speaker to a moving body member. Soon the latter procedure will be used. If more than one body member is involved in an operation, different frequency signals could be used to differentiate the different members involved. At present, a relatively small electrostatic speaker is being used, but a smaller speaker should be available soon.

The perpendicular factors of the frequency changes caused by the motion of the speaker are picked up by the three microphones. The block diagram (Fig. 1) shows only one microphone and its corresponding circuit; the same circuitry would be used for the other two microphones. When the speaker is in motion, the frequency of the sound received at the microphone will be 20 kilocycles per second plus or minus the Doppler difference. Since the voltage level of this received signal is quite low (15 microvolts), it is sent through a preamplifier composed of five tuned amplifier stages. The 20-kilocycle signal, plus or minus Doppler-difference frequency, is mixed with a 21-kilocycle reference signal (generated by a crystal-controlled oscillator). A 1-kilocycle signal, plus or minus the Doppler-difference frequency, is obtained. This is a usable signal for conversion to voltage. It is sent through a tuned amplifier stage to increase the voltage and then to the converter.

In the converter, the sine wave is first changed to a square wave. This is done so that the signal which drives the thyratron (2D21) is independent of the amplitude of the incoming signal. In addition, the thyratron must be driven by a signal of high amplitude and short time duration. This can be obtained by differentiating the square wave, but it cannot be obtained directly from the sine wave. These pips are sent into the thyratron whose circuit is arranged so that its d-c voltage output is directly proportional to the frequency of the input. Since some of the input pulses remain on the output voltage, the signal is sent through a π section filter. This d-c voltage is directly proportional to the velocity of the speaker. (The d-c output voltage is proportional to the input frequency, and the input frequency is proportional to the velocity of the speaker through the Doppler-effect relationship.)

The d-c voltage is sent to a d-c amplifier to increase the voltage and then to the velocity recorder. The amplified d-c voltage is also sent to an electronic differentiator, whose output voltage is proportional to the acceleration and deceleration of the speaker. This signal is sent to the acceleration-deceleration recorder. The amplified "velocity" voltage is also sent to an electronic integrator whose output voltage is proportional to the displacement of the speaker. This signal is sent to the displacement recorder.

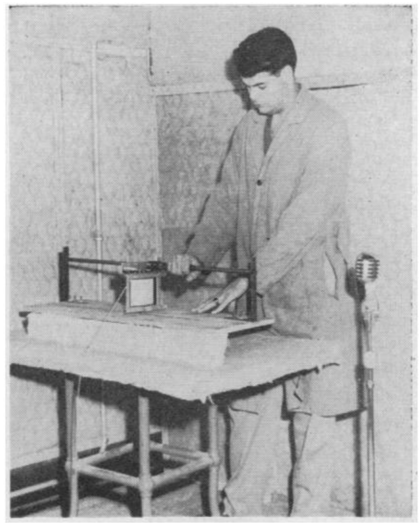

Fig. 2. Test setup for determining UNOPAR reliability of measurement for one-plane motions.

Direction of the motion is determined from the voltage variations above or below the voltage output of the 1-kilocycle signal input. A voltage larger than this indicates a motion toward the microphone, and a smaller voltage indicates motion away from the microphone.

For any motion, three records of velocity, three of acceleration-deceleration, and three of displacement are obtained. The three records for a given measurement unit are combined into the absolute total by electronic vector summation. The calibration circuitry is designed to generate sine-wave signals of the proper frequency to check the velocity and acceleration maximum displacement values.

A 12-channel d-c oscillographic recorder is used to plot each one of the individual factors and the resultant components of velocity, acceleration-deceleration, and displacement. The recorder is capable of plotting information at a constant maximum speed of 125 millimeters per second (5 inches per second), thus providing an accurate timing record for every motion.

The present electronic equipment and recorders are fairly large. Development of the equipment indicates that there will be a sizable reduction in the amount, size, and weight of the necessary components.

Accuracy

Tests for reliability of measurement were made for one-plane motions (there is no criterion for three plane motions) with an accelerometer as the criterion source. The test setup is shown in Fig. 2. Chi-square and correlation were used to check the size and shape of UNOPAR, criterion velocity, and acceleration-deceleration plots. Chi-square probabilities of 0.99 and above and correlations of 0.99 and above were obtained, indicating excellent fits for the curves. Additional verifications were made with the standard deviation for percentage of error from the accelerometer plot for the maximum (peak) velocity, maximum acceleration-deceleration, and time for a series of motions. For velocity, the standard deviation was 1.08 percent; for acceleration-deceleration, 2.17 percent; for time from velocity, 1.06 percent; and for time from acceleration, 2.79 percent. These results indicate excellent measurements (there is some evidence that part of the errors obtained were due to the accelerometers, not to UNOPAR).

An indication of the type of information available through the use of UNOPAR is shown in Fig. 3. The motion was performed on the test set-up of Fig. 2, and the motion was stopped by the support at the end of the motion. The velocity plot in Fig. 3 shows the direct response of the device to a motion of this type.

Uses

Many work-measurement benefits can be found in the application of UNOPAR to problems of studying operator performance. Information about every motion will help establish the concept of a standard or normal level of performance.

Fig. 3. Drawing of a tape that recorded the motion of the test speaker in one plane. The speaker was at rest at the left. As the speaker started to move, the velocity charted increased rapidly. There was a very slight slowdown of velocity until the speaker hit the barrier. At this point the velocity dropped immediately, and the slight rebounds of the hands and speaker are indicated by the wavy motions after the drop. The motion was recorded on the tape running at the fastest speed.

Much work must be done to combine all these measurements into an over-all concept of operator performance. However, through experimentation and research, this problem may be solved in the near future, for UNOPAR now makes measurements that could not even be roughly approximated in the past.

Other problems dealing with work, or with what a human being does, may be solved with the aid of UNOPAR. A brief review of some possibilities will show the widespread adaptability of the measurements. [For a complete discussion of all aspects of the UNOPAR and its potential uses, see G. Nadler, *Motion and Time Study* (McGraw-Hill, New York, 1955), pp. 417–428.] The instrument may not be capable of summarily solving all problems outlined in subsequent paragraphs, but at least much light may be shed on these problems.

Let it be assumed that a time standard is established for a definite method and that it is essential to accurately describe the method. Many disputes arise today because of the use of qualitative methods of description. It is difficult to determine when a change in time standards is fair if there are no ways of computing values of percentage variations of methods. Quantitative measurements from UNOPAR may help to establish a procedure for detecting changes in method.

If the permanent record of displacement and position gives new information about motions, motion patterns, and motion paths, better decisions can be made about the correct motions for an operation as well as about the correct sequence of these motions.

Frequently, two operators, using what is considered to be the same method, differ considerably in performance. An accurate measurement of their motions may disclose subtle differences in performance that are not readily observable. With the information about individuals and individual differences obtained by using UNOPAR, it may be possible to train poor operators to improve their performances.

Time units on the UNOPAR records are as small as 0.000133 minute, measured on a recorder tape moving at a speed of 125 millimeters per second at 1-millimeter intervals. Even smaller time units can be obtained. When this level of accuracy is not needed, a slower speed can be used. Measurement of the elapsed time required to complete a motion or an operation is a great deal more accurate than usual timing procedures, especially since full actual motions are recorded, not just end-points determined through an individual's reaction time and other errors.

The difficulty of an operation affects the pace of an operator. Because difficulty and pace are interrelated, UNOPAR can help obtain accurate information about difficulty.

There are many standard data systems (compilation of past standard time information for application purposes without direct study) in use today. There is some controversy about the validity of these systems. Because times for motions or groups of motions form the bases for these systems, UNOPAR can check into their assumptions.

Even if there were no other advantages to be gained through the use of UNOPAR, one of the most readily apparent is that exact information about each and every motion of each cycle is recorded, whereas other procedures of motion and time study or work simplification and measurement obtain only over-all information. The ability to provide specific information is a basic requirement for any good measurement procedure.

However, the use of UNOPAR will not be restricted to industrial engineering alone. As is pointed out in a foregoing section, measurement of human performance is needed in other areas, such as psychology, physiology, sociology, biomechanics, education, and physical education. Within the near future, UNOPAR should help solve many of the problems in each of these areas by providing accurate information about motions and performance.

With this objective information, management and labor should benefit through more accurate information for all the areas in which time standards are important.

It is important to warn that UNOPAR has not been fully developed and that, when it is, it may not be capable of everything expected of it. However, it represents such a radical change in the concept of measurement of human performance that we think it can be expected to revolutionize many aspects of industrial engineering. We believe that the information available from UNOPAR is so much more accurate than that available from other procedures or techniques that much more can be learned about the performance of a human being than ever before.

Phase Microscopy 1954–56

Oscar W. Richards

Phase microscopy has become a recognized standard method. Few publications now refer to it in the title, and a complete listing of papers is no longer possible. Some of the uses of phase microscopy in the first 2 years of the second decade since we demonstrated the first American instrument (*1*) are summarized here as well as a few papers missed in the preview review (*2*). Details on the function and use of the instrument in various fields are available (*2, 3*).

General, Theory, and Instruments

While the previous review was in press, Wilska (*4*) described the new Reichert Anoptral phase microscope, which is unique in using a less reflecting material than evaporated metal for the diffraction plate. Bright contrast is used so that differences in the refractive power of the specimen are better revealed (*5*). The outside diameter of the diffraction plate is made larger for increased resolution. The image is slightly yellowish, less harsh, has less glare, and photographs well, as is shown in the varied photomicrographs of Schüller (*6*).

A bibliography has been published by the firm of Winkel (*7*), Fröhlich has summarized some German and Swiss work (*8*), and information on the theory and use of phase is included in the symposium reported by Françon (*9*). General discussions in Dutch have appeared by Bok (*10*) and Bogaerdti (*11*). Czerny (*12*) expresses amazement that phase was not discovered between Abbe and Zernike, apparently unaware of the work of Bratucheck and of Conrady and Rheinberg (*13*). Zernike (*14*) tells how he discovered phase about 1930, and some general and medical applications are mentioned by Crossmon (*15*).

Wolter (*16*) summarizes much of his work and relates phase to *schlieren* and other methods, and Barer (*17*) summa-

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