THE UNIVERSITY OF MICHIGAN

INDUSTRY PROGRAM OF THE COLLEGE OF ENGINEERING

A DESCRIPTION OF THE ELECTRONIC DATA COLLECTOR AND THE METHODS OF ITS APPLICATION TO WORK MEASUREMENT

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INTRODUCTION

The purpose of this paper is to describe the Electronic Data Collector and the methods of its application to work measurement in the area of predetermined motion times. The collector was designed and built under the supervision of the Department of Industrial Engineering of The University of Michigan to aid in research work being done for the MTM Association for Standards and Research.

The primary purpose of developing the collector was to overcome limitations in the existing techniques used in the field of work measurement. The difficulty in handling the large amounts of data utilized in the study of predetermined motions made it necessary to develop new and improved techniques. The approach that was taken was to develop a system which would be capable of recording large amounts of data with high orders of accuracy, from both industrial and laboratory situations, and to perform the necessary operations to enable the information to be readily analyzed. A previous paper(4) is an attempt to present and compare the relative merits of the research techniques presently used in predetermined time systems.

As a result of these design requirements, we have developed a portable Electronic Data Collector (hereafter designated as EDC and illustrated in Figure 1) that uses transducers placed in the work area as a source of signal inputs, records the elapsed time to the nearest 1/100,000,000 hour of one or more elements in sequence, and stores the information on a punched paper tape. The collector was completed in

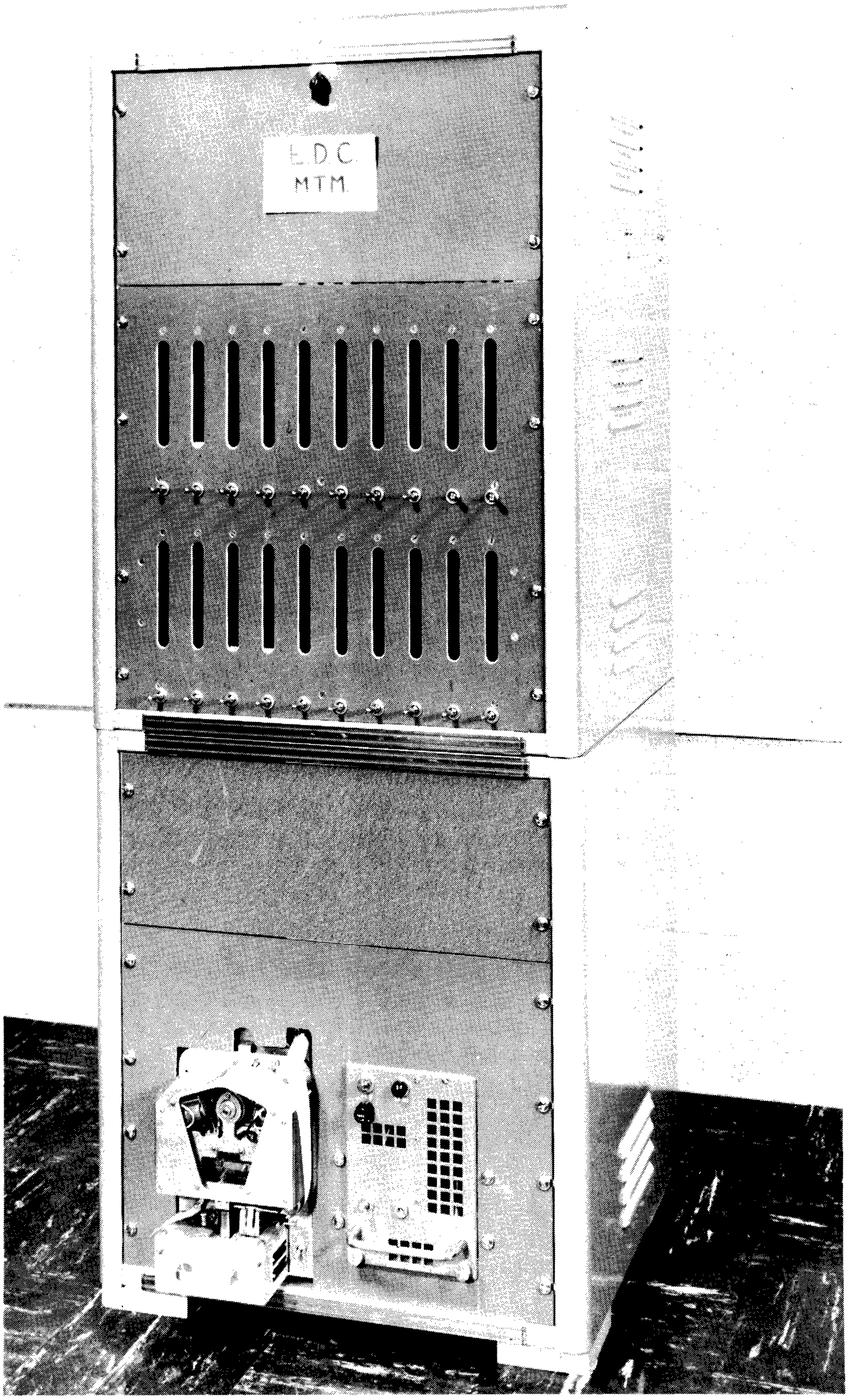

Figure 1. The Electronic Data Collector Showing the Counters, Tape Punch and Power Supply.

December, 1960, and is presently being used successfully in the study of the learning time associated with short cycle operations under the auspices of the MTM Association.

The use of electronic methods to record time values is not new, (1,2,3,4,6,7). Previously developed equipment was not considered to be completely satisfactory for our purposes for a number of reasons. Perhaps the most serious reason(s) was the lack of portability or capacity, or both. The establishment of predetermined times makes it necessary to collect data in large amounts from actual production as well as from laboratory situations.

The present EDC is a vacuum tube computer which weighs approximately 200 pounds but can be transported in two 100-lb. units. A transistor version could be contained in a large size suitcase with a weight of no more than 50 pounds. Since the techniques and equipment have been developed to obtain information directly from industrial operations, the potential uses of this equipment go beyond the establishment of predetermined times. Other uses are indicated in References 4 and 5 and at the end of this paper.

Figure 2 is a block diagram of the EDC. To give an overall picture of the construction, the following is a brief description of the three main functional groups of the collector:

> The Input Group[1] tests and conditions electrical input signals from the transducers and with these signals performs logical operations which describe the time relationship of the interval (element) under study.

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1 The underlined words refer to sections of the block diagram as shown in Figure 2.

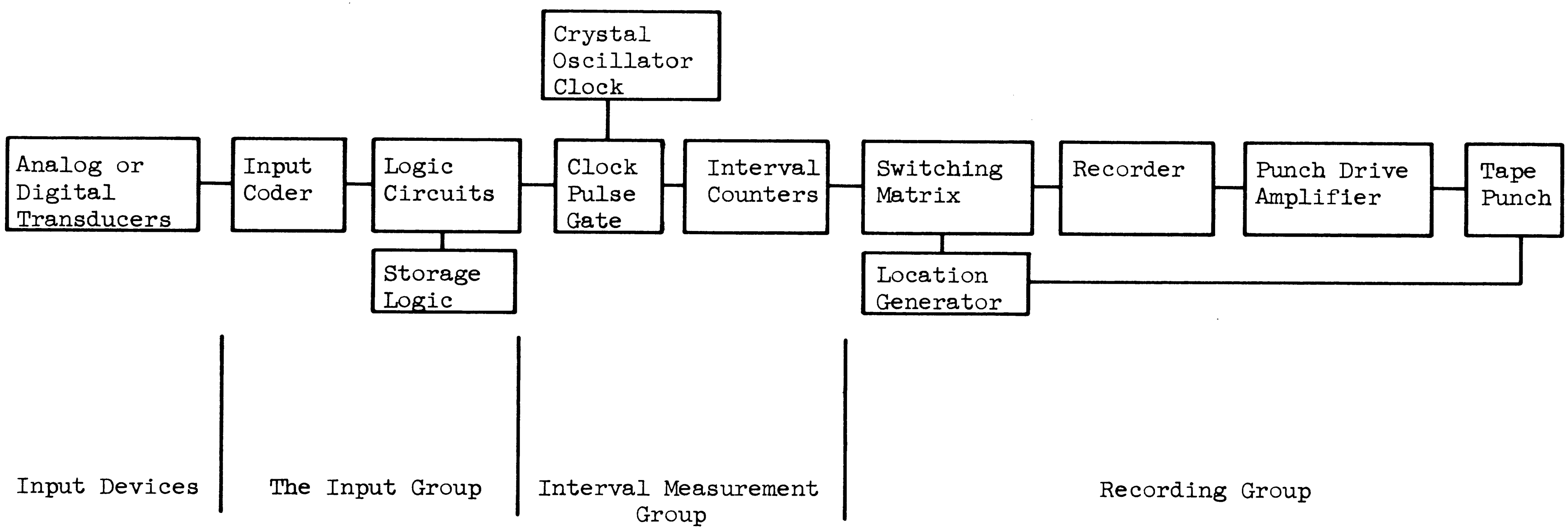

Figure 2

Block Diagram of the Electronic Data Collector.

The Interval Measurement Group consists of a clock which is a precision crystal oscillator, feeding pulses at a known rate through gates (electronic switches) controlled by the input group to counters which sum and store the number of time units in the interval under study.

The Recording Group on command automatically places the data stored in the counters on punched tape after appropriate recording and then resets the counters for a new cycle.

Following is a more detailed description of the three main groups of the data collector as well as the necessary input devices.

THE INPUT GROUP

The Input Group synthesizes time intervals from combinations of transducer outputs.

Connections to the EDC are made electrically through the Input Coder which tests the input signal and generates a standard output signal suitable for use in the logic operations. The test is performed by a trigger circuit which tests both the amplitude and the sign ($\pm$) of the input signal. The trigger circuit allows the machine to utilize analog signals such as velocity and acceleration in addition to the simple on-off signals generated by switches. The output of one input may be used to control several logic circuits.

The Logic Circuit consists of a plug board where signals from the input coder are programmed to operate the logic circuitry. The way the logic circuits are programmed defines the beginning and end points of the time interval under study (Figure 3).

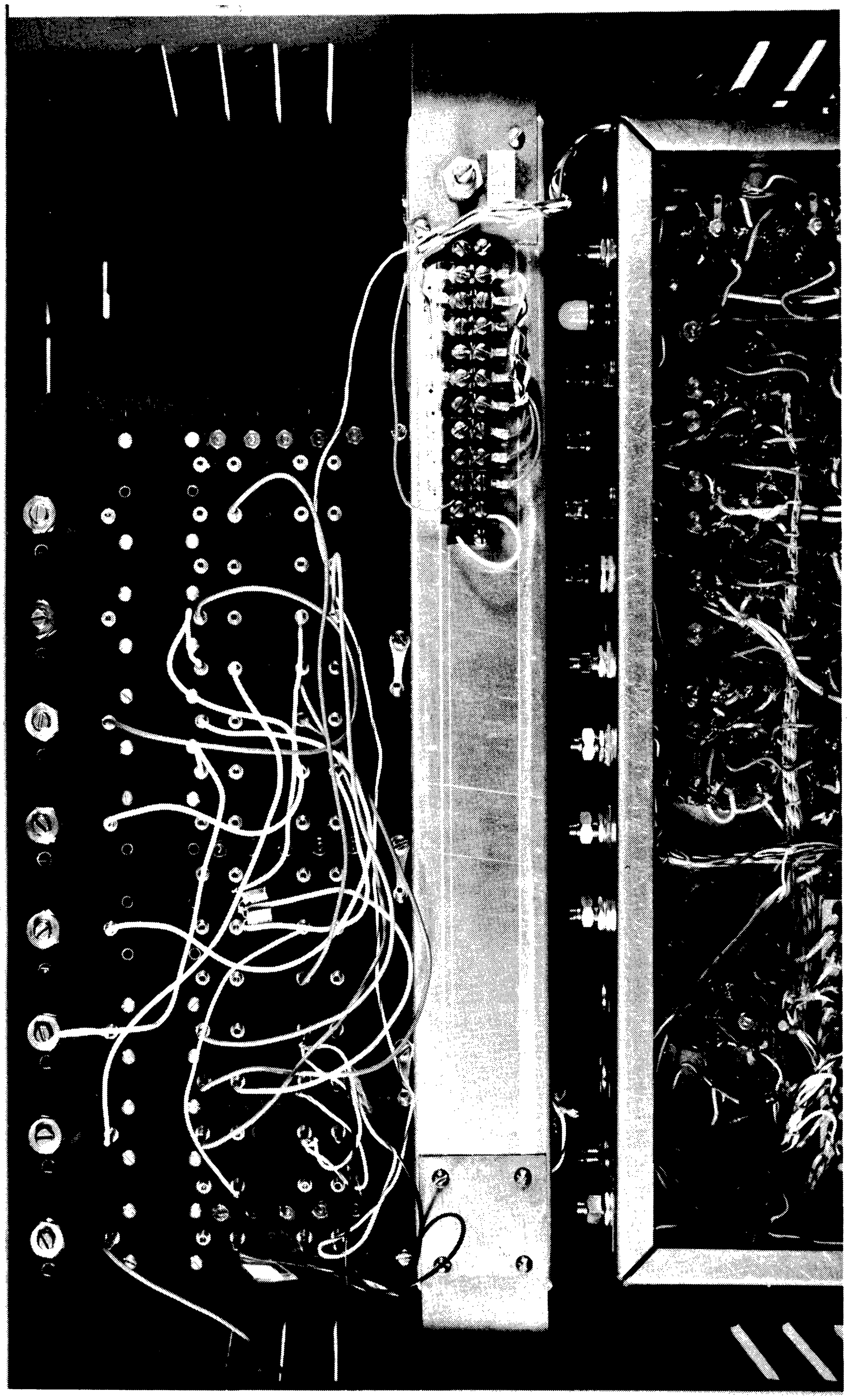

Figure 3. The Logic Circuit Plug Board.

Where inputs are in the form of pulses, such as from the interruption of a photocell, storage logic is necessary. The pulses are used to trigger flip-flop circuits which exist in one or the other of two states depending on the last signal pulse. Thus, on or off conditions can be maintained even though only a momentary activation is available.

INTERVAL MEASUREMENT GROUP

The basis for the time measurement is similar to that of a stop watch; however, instead of counting the mechanical beats of the escapement wheel, we count the beats of a precision electronic clock. This clock is a quartz crystal oscillator operating at 27,777 cycles per second for accuracy to 1/1000 TMU (1 TMU = 1/100,000 hr). Outputs are also available at 1/10 and 1/100 of this rate when higher accuracy is not necessary.

The output from the clock in the form of pulses is fed to gating circuits. The gates act as switches controlling the number of pulses that pass through to the counters. The number of pulses that are passed is a measure of the time the gate is in operation. The gates are controlled directly from the Logic Circuits.

The outputs from the various gates are connected to the time Interval Counters. The counters consist of 20 decade units or registers each counting 0 to 9. Through the use of a plugboard and switches, individual counters can be combined into groups of the desired digit capacity. This flexibility of arrangement is desirable in obtaining the maximum utilization of equipment.

RECORDING GROUP

One of the basic criteria in the design of the EDC was the incorporation of a high speed recording device. A paper tape punch with a recording rate of 60 characters per second was selected (Figure 4). Recording is accomplished in the following manner.

The counters with the stored data are connected to a Switching Matrix which connects the counters, one at a time and in sequence, to a Recoder where a suitable code (language) is generated for recording. This switching (reading) process occurs under the control of the Location Generator which reads the data to the punch at its maximum punching rate.

Recoding serves the purpose of converting the special language of the counters into a form compatible with standard data processing equipment. Since several "standard" languages are available, two have been incorporated in this equipment. Both the 5 channel teletype and 6 channel Flexowriter codes are used.

INPUT DEVICES

Several classes of input devices have been used by the authors in both laboratory and industrial situations. The following list is by no means complete as each new project undertaken may suggest new and novel methods of approach. However, it will serve to indicate the types of devices that have worked successfully.

Position indicators--These indicators are used for determining when a motion arrives at or passes a fixed point. This is similar to the timing of a race by observing the starting and finishing lines.

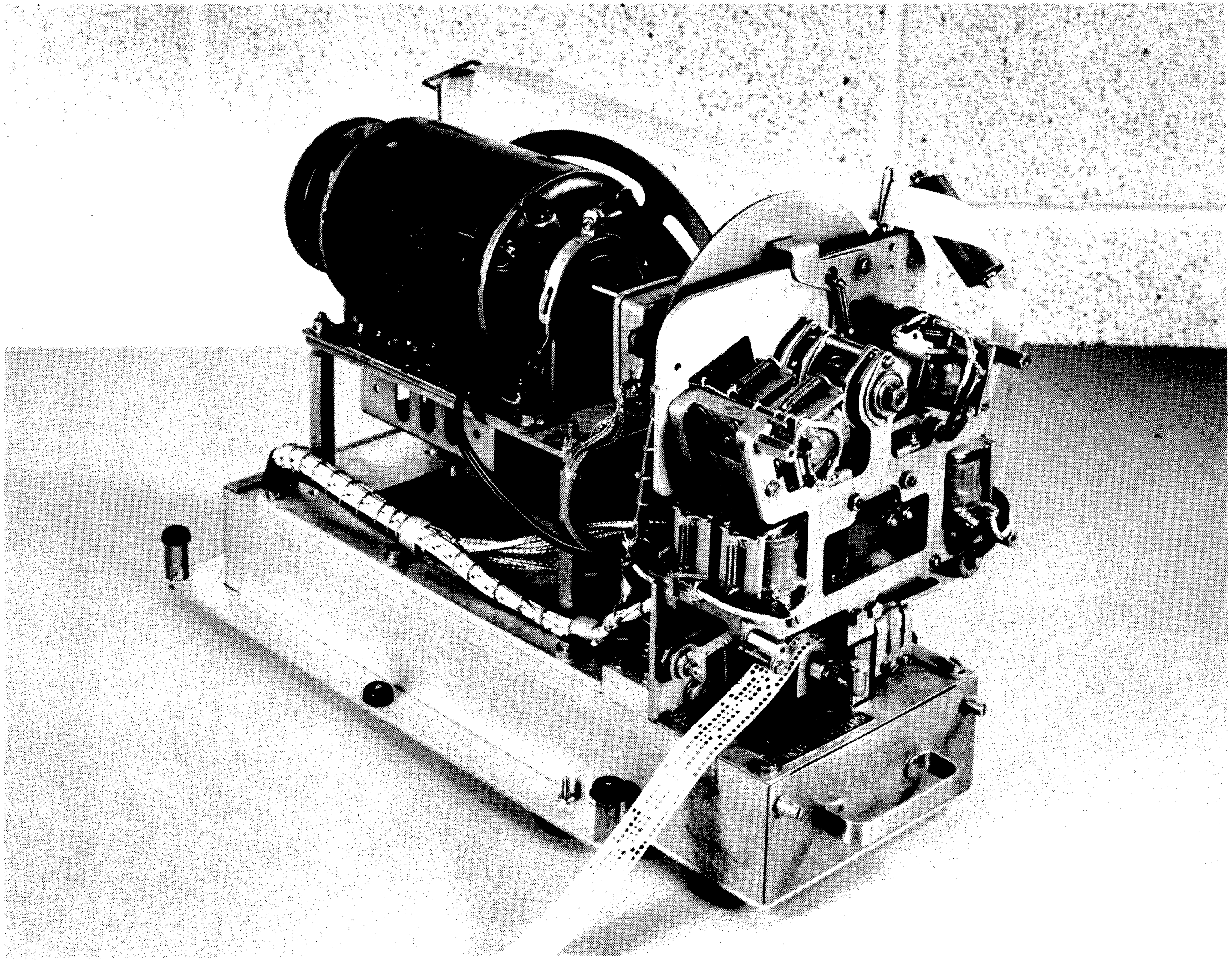

Figure 4. The High Speed Paper Tape Punch Used in the Electronic Data Collector.

1. Switches--Small easily actuated switches such as micro-switches can be positioned in a work station so as to be tripped by the placing of a piece of stock or the movement of a lever.
2. Contact Devices--These indicate the touching of an object by an operator by providing a conductive surface in the work station which is electrically insulated from the ground. The devices are connected to a sensitive circuit, such as a balanced impedance bridge. This type of measurement is useful where grasping or positioning motions cause contact between objects. Figure 5 is an illustration of stock bins that were instrumented by this method.
3. Photocells--The interruption of a light beam indicates the presence of an object or the operator at a definite location. The photocells are placed so the light beam will be interrupted by transporting motions. Figure 6 is an illustration of their use to determine the time to obtain and position the channel pin. For the positioning element the photocells are activated by blocking light to the hole. The photocells are located under the table. The time to obtain the pin from the bin is determined with the two photocells in the side of the bin.
4. Potentiometers--These devices convert linear or angular positions into analog voltages. To determine whether a handle or shaft is displaced a certain distance, the

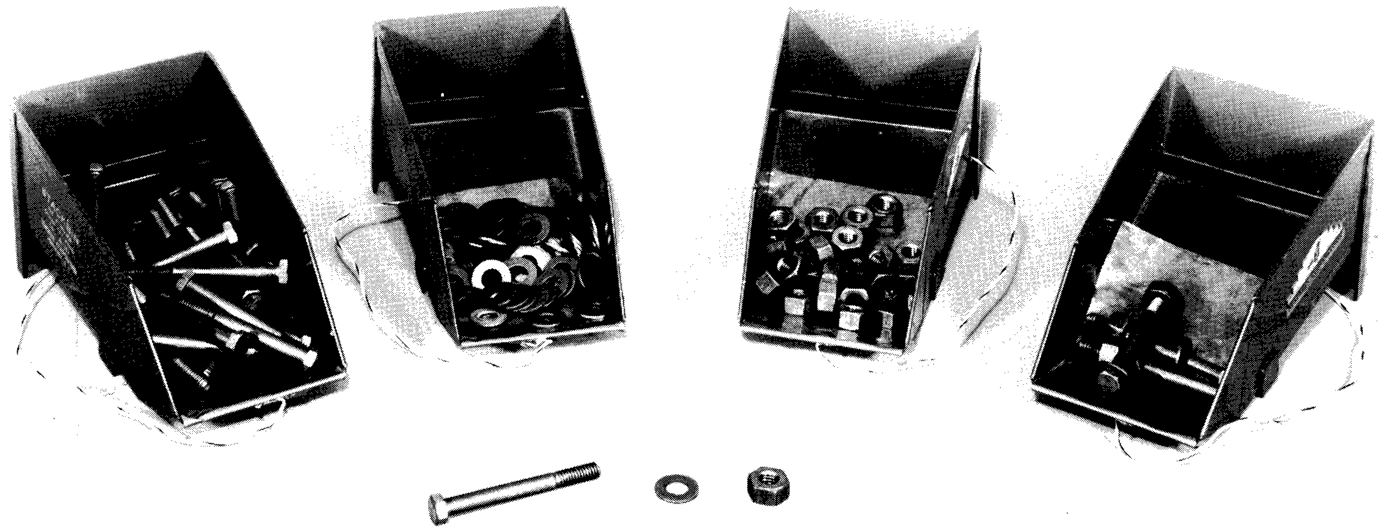

Figure 5. Stock Bins Used in a Simple Assembly Operation Which Have Been Instrumented Through the Use of Contact Devices.

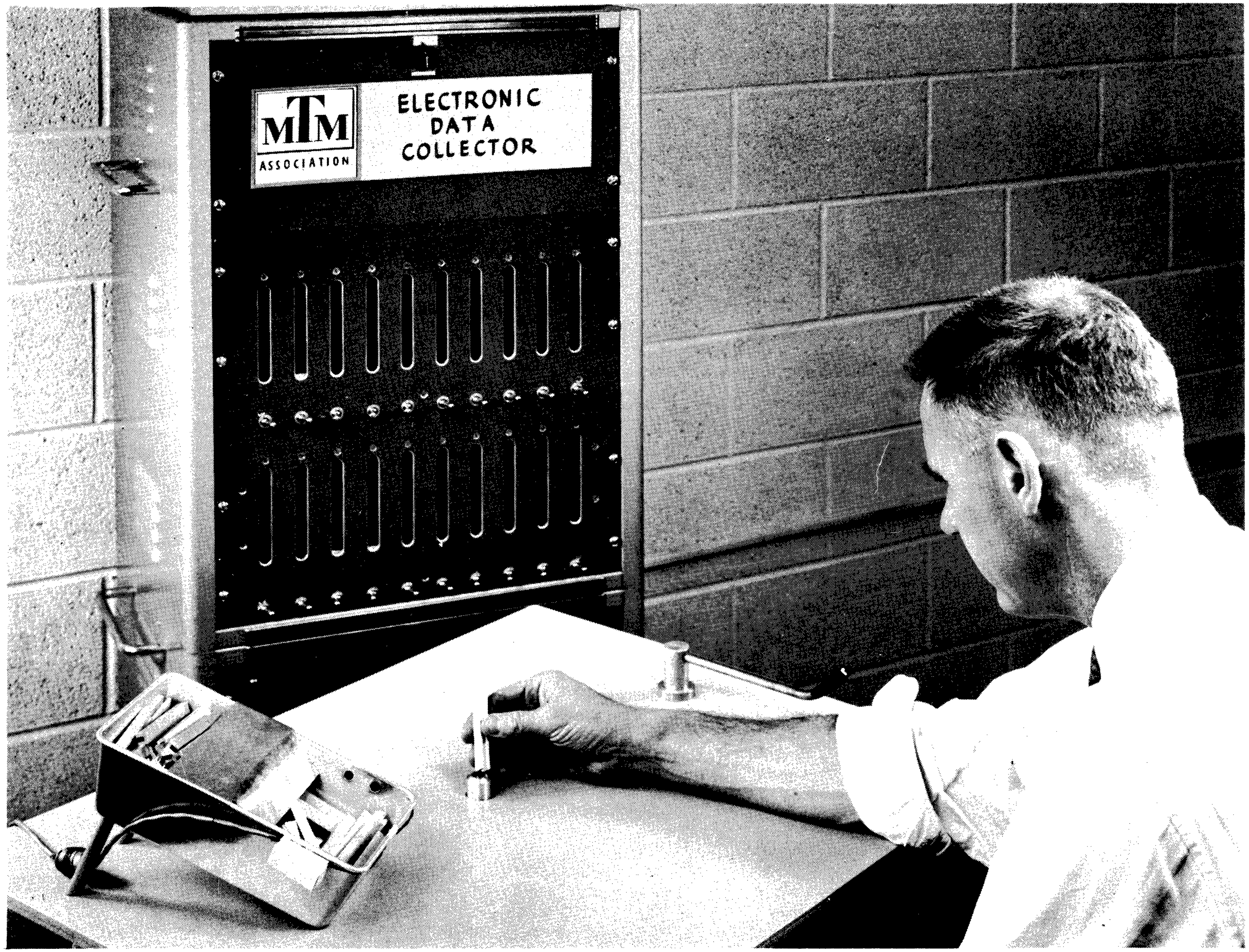

Figure 6. An Illustration of the Use of Photo Cells to Determine the Time to Obtain and Position the Channel Pin.

potentiometer can be attached so that a change in position can be measured electrically.

5. Deflection Devices--A leaf spring with a strain gage attached can be used to measure distance. A position change in an object, such as a handle, is used to deflect the spring. The output from the strain gage, which is related to the strain caused by the deflection of the spring, can then be calibrated to give the position of the handle.

Other Types of Indicators

1. Strain Gages for Force Determinations--A very small gage can be cemented to an object, such as a lever, for the purpose of determining the forces acting on that object. The strain gage circuit gives an analog voltage output which triggers an input circuit whenever the force rises to a predetermined level or levels.
2. Accelerometer--A device which gives a measure of the acceleration being experienced by an object on which it is placed. Small models can be located easily and inconspicuously (Figure 7). The major limitations are its single axis of sensitivity and the difficulty of determining the orientation of this axis when experimenting with members of the human body.
3. Pressure Sensitive Paint--A material which changes its resistance when it experiences a force on its surface.

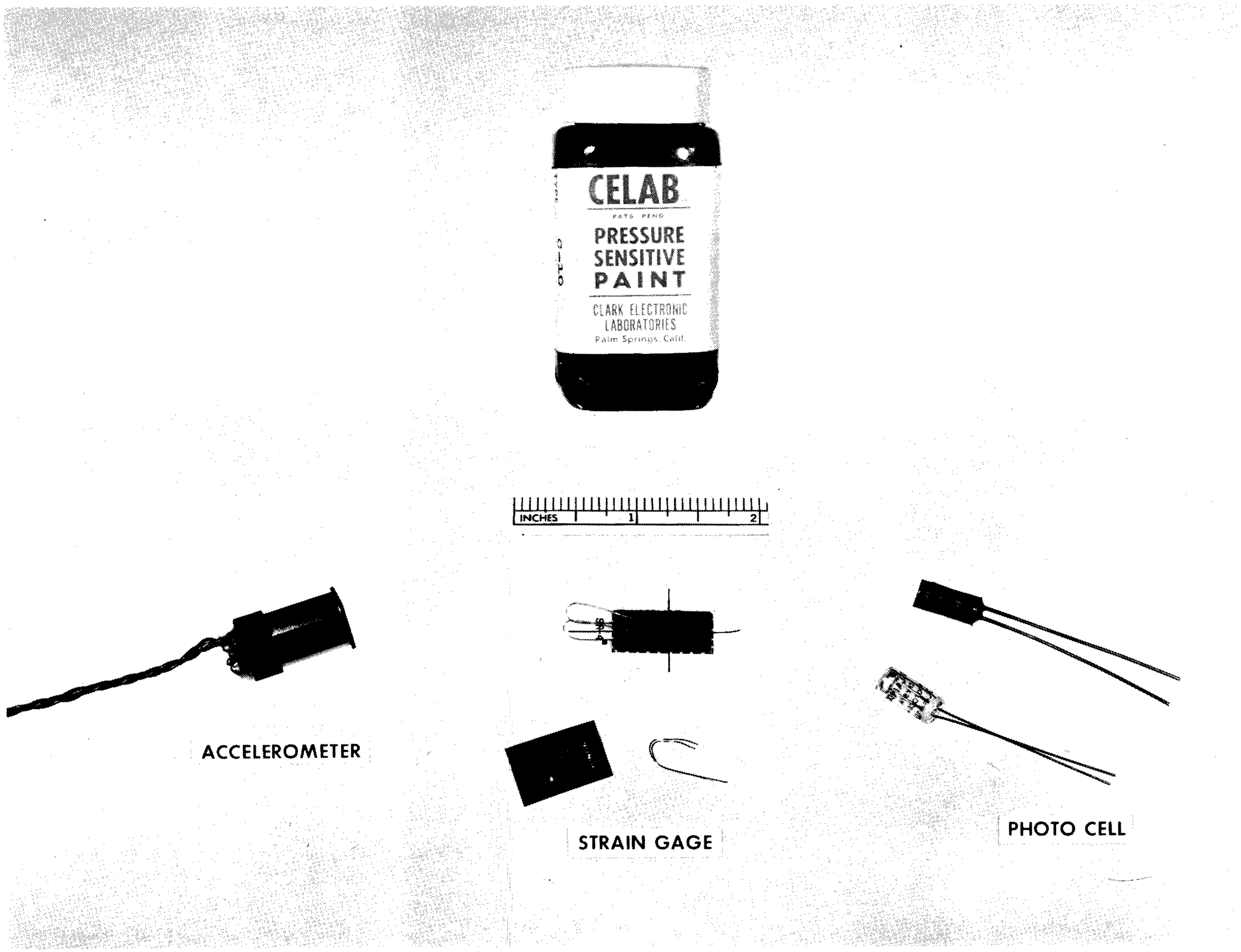

Figure 7. Various Input Devices Suitable For Use With the Electronic Data Collector.

This material is applied by painting it onto a conductive surface over which a second electrode is placed, thereby forming a sandwich. The resistance of the sandwich is a function of the force being exerted on the sandwich. An example of an application would be the case where it would be desirable to determine when an object is removed from or placed on a workbench. The sandwich could be placed under one or more of the legs to get the desired information.

METHODS OF USING EDC

The normal method of using the EDC for the analysis of elemental time values is as follows:

1. The operation on which data is being collected is observed in order to determine the following:
   a. The motion pattern followed.
   b. The beginning and end points of the elements under study.
   c. The approximate duration of the elements.

   Where the elements under study are very small or where complex motions are involved, it is sometimes desirable to take a high speed motion picture of two or three cycles of the operation in order to instrument the operation properly. In those instances where forces need to be determined, strain gages or other transducers are placed in appropriate locations in the work station and graphs of the forces used are made with a graph recorder.

2. Input devices such as those discussed previously are then selected to indicate the beginning and end points of the elements under study.
3. The EDC is programmed to record the elemental time values and is connected electrically to the input devices. The collector itself can be located at a remote location and out of sight of the operator if it is desirable.
4. Once the operation is instrumented and the collector programmed, data can be collected either continuously of intermittently for as long a period as one wishes. In an industrial operation, it is usually desirable to allow the operator to become accustomed to the environment introduced by the installation of the input devices and their associated wiring. We have not encountered a case where the instrumentation has interferred with or been objected to by the operator.
5. The data that is generated and punched on paper tape is presently put through a tape-to-card converter and then through the University's IBM 709 for reduction and analysis. In the near future, the tape will be used as direct input to the Industrial Engineering Department's LGP-30 Computer for the same purpose. Standard statistical computations such as the mean, variance, correlation, regression and difference tests are performed on the data generated by the EDC.

POTENTIAL USES OF EDC

The development of a portable, compact data collector such as the transistorized version of the present EDC would seem to have many potential uses in the industrial engineering field. There are many cases where large amounts of data will be necessary to further our understanding. Because of this, the following areas could conceivably benefit by the use of EDC or similar equipment.

1. Machine Interference Studies--The collector can be programmed to record the occasions on which a number of machines are down at the same time. The set-up times and run times could also be recorded. This type of data could then be used to determine the proper allowances where one operator is running two or more machines.
2. Fatigue Studies--The collector is capable of recording elemental and cycle times over long periods. Since the elemental and cycle times should be relatively easy to obtain in large quantities, the analysis of trends could be much more meaningful and complete.
3. Learning of Manual Skills--The elemental as well as over-all cycle times for operators performing repetitive operations could be collected and analyzed to determine how people learn. The EDC equipment is presently being used on this type of research to determine the number of cycles necessary to attain an MTM standard.[5]

4. Work Sampling Studies--The collector, with slight modification, could be set up to randomly sample various factors such as rate of production, machine condition (running or stopped) and whether or not the operator is at his work station. The information could be obtained with the EDC operating unattended. The data would be in a form that could be easily analyzed.

5. Integrated Data Processing Systems--Equipment such as the EDC could be used to obtain the basic production information in a form that could be directly fed into a data processing system. This equipment could act as a buffer to a computer because it could collect the necessary production information which could then be stored on a punched paper tape and fed into the computer at appropriate intervals.

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