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ABSTRACT

There is a growing need for instrumentation which can enable us to observe and compute phenomena that take place in time. Although problems of observation, computation, interpretation and categorization vary from field to field and from problem to problem, it is possible to design an instrument for use in any situation where time-variables have to be measured as duration and frequency,. The Polychronometer is suggested for such purposes. It is essentially composed of ten paired counter-timer sets each operated by a separate key. The ten keys are set in a keyboard which is plugged into the control box, each key being designed for a different finger of the left or right hand. A few hours of practice is sufficient to give an observer proficiency in operating the key board, sufficient to adapt to the rapidity of moving events. Further work is being done to develop different polychronometric techniques for the analysis of behavior. (Author)

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POLYCHRONOMETRY :

the study of time variables in behavior

WILLIAM FRANCIS MACKEY

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International Center for Research on Bilingualism

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POLYCHRONOMETRY: THE STUDY OF TIME VARIABLES IN BEHAVIOR

William F. Mackey, CIRB, Laval University, Québec.

Introduction

The history of science is largely the history of measurement. Most developments in measurement have in the past been associated with the physical sciences. Since the turn of the century, however, advances in the social sciences have been associated with statistical methods. Most of these have been applied to the behavior of populations, rather than to detailed observations of individuals or small groups, and their behavior during observable events in their lives. It is the purpose of this article to present a method and an instrument for the analysis and measurement of such observable events.

Although there are established ways of measuring changes in environment, there are as yet few standard measures for variables of events that take place in the environment. Environmental changes in such things as temperature, humidity, radiation, and the purity of air and water are measured daily, and these measurements are used to solve a host of practical problems. We no longer rely on our feelings to find out whether a place is warmer or damper than another; we rely on such instruments as thermometers, hydrometers, barometers, and the like. The use of such instruments permits us to record measurements of things that are continually changing, enabling us to come to a number of general and practical conclusions.

On the other hand, in talking about events we have very few possibilities of measurement. A notable exception is the stock market where the selling and buying activity of individuals is recorded with precision and rapidity. In less than a few hours we can know how many shares have changed hands in such cities as London, New York, Toronto, and Tokyo, the value of these shares, and whether their price has gone up or down. But when talking about such fields as radio and television, sports, theater, ballet, and other forms of activity, we have nothing more than individual impressions and opinions, which may vary from individual to individual, when analyzing

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the same event. Opinions may vary as to how much action there was in one event as opposed to another, whether someone's performance was better than someone else's, and the like, because we have no objective way of analyzing and measuring the variables. The same symphony, opera or play presented a number of times, each time with changes in the tempo of its components can give a series of entirely different impressions. In reacting to the merits of each we are likely to shrug our shoulders and resign ourselves to the dictum *de gustibus non est disputandum.*

In observing people, we can get some idea of their mutual interrelationship simply from the duration and frequency of the contact between them and the distribution of their speech and gestures. These, it would seem, should, with the aid of operant methods, lend themselves to behavioral analysis. And such analysis when quantified may well have predictive power, since the behavior of organisms tends to follow fixed patterns.

1. The Need

There is a growing need for objective operant methods of evaluating such performance products as lessons, interviews, television programs, motion pictures, sports events, riots, battles and other recordable happenings. Job evaluation is another field in which quantification is important if it is to fit the right person to the right work. For example, it is important to discover whether a person's tempo of interpersonal relations is the sort as to make him happier and more efficient as a teacher, an office worker, or a salesperson. And even within a single job category the quantification must be sensitive enough to establish a relationship between the tempo of the individual and the tempo of the job. Personnel managers have observed that one salesperson may be happier selling a lot of small items whereas the tempo of another salesperson may fit him better for selling large, expensive items where more patience and tact may be required; for success in selling depends on what is being sold by whom. The difference in characteristics needed to succeed in two different jobs often accounts for the fact that so many promotions become failures, as is often the case when a successful production worker is promoted to the job of supervisor.[1]

The need for quantification of personal interaction has also been seen in the analysis of interview material, including psychiatric interviews. The relative amount of speech activity on the part of the interviewee can be correlated with personality traits; so can the variability of the speed of talking.[2]

Interaction analysis has also been used in the evaluation of teaching performance.[3] The relation between the amount of student talk has been considered significant. So has the distribution within a lesson of direct and indirect teaching -- of lecturing, criticizing or giving directions, as opposed to questioning, encouraging, making use of the students' ideas and acknowledging their feelings. The amount of talk initiated by the student as compared to the amount of talk resulting from direct reply to the teacher's questions has also been used as an index to characterize a lesson.

It would seem, therefore, that elaboration and improvement of methods of quantification of time variables in observable phenomena could result in advances in the behavioral sciences. The variables, however, must first be isolated and selected.

2. The Problem

All events have variables. These variables can be isolated and subjected to measurement. They can be isolated in relation to the problems we have to solve, or the information we seek. They can be analysed as functions of such evaluative concepts as stability, stimulation and interest. These functions can be measured on a time scale, giving us the amount of time distribution for each variable.

Before any sort of evaluative conclusions are possible, however, the event must first be accurately observed, the variables isolated and measured, the results interpreted and the functional categories established. There are therefore four related problems the solution of which depends on the field, the situation and the objectives. They are: the problem of observation, the problem of computation, the problem of interpretation and the problem of categorization.

2.1 The Problem of Observation

Whether the event is observed directly as it is taking place or indirectly as a recording or verbatim report may depend on the possibility of obtaining information that is accurate or abundant enough to be worth while.

Direct observation -- known or unknown to the subjects being observed -- was all that was possible at the period when time-and-motion studies were first launched in industry. The image of the time-and-motion observer has disturbed labor organizers. As late as the 1960s, aged trade unionists were still haunted by visions of the furtive efficiency expert with his stop watch and notebook. Yet no one seemed to object to the tallying of sports analysts and drama adjudicators.

As recording facilities became more generally available, indirect observation through recorded material gained in popularity. These facilities permit a choice between verbal recording, vocal recording, cinematography and videotaping.

Verbal records, especially the verbatim stenographic transcripts of the court clerk have been of limited use in the study of duration and frequency of events, since they have recorded only what can be written according to the usual conventions. Vocal recording, however, by means of disk and tape recorders, registers not only what is said but also how it is said, including the hesitations and silences, in real time. These have been used for the analysis of psychiatric interviews.[4] If, however, one is interested more in the actions than in the speech of the subjects, simple cinematographic records may be what is required. This type of recording may also be used in the analysis of interview material.[5] The most complete record, of course, includes both the sound and the image. Both sound motion pictures, and especially videotape have become widely accessible to record for later analysis events in many different fields.[6] The superiority of videotape is that it gives the choice of either erasing the record once it has been analysed, or of conserving it as a document or a model for purposes of training and research.[7]

The means of observing the event -- directly or indirectly - is only the beginning of the problem of description and analysis. Once we have the record, we must arrive at a means of compiling and computing the relevant data which it contains.

2.2 The Problem of Computation

What are the objectively measurable components of an event? The chief ones are time, sound, movement and contact. Since both sound and movement must take place in time, they can be described and measured in temporal terms as continua of frequency of occurrence and duration. All phenomena distributed in time can be described in terms of frequency distribution and relative duration; these can be correlated with related phenomena as being significant, causal or diagnostic.

In analysing configurations of movement and sound as they unroll in time, one must know what units to look for and how to count them. The units themselves will depend on the type of event, the field of knowledge and the purposes of the analysis. If one is studying interview transactions one may be interested only in what a person says (content analysis).[8] Or one may be interested in how he says it (behavioral analysis), and this could include the person's rate of speech, the amount of talking and the length and number of silences and interruptions.

A complete count of the time-units includes a record of their duration and frequency. The duration can be computed in arbitrary units of time -- in minutes or seconds. Some researchers have used units of one minute;[9] others have been able to limit themselves to 30 seconds,[10] five seconds,[5] and even to three seconds.[11] Or the duration may be computed in real time.[12] Both methods can be used with or without special recorders of elapsed time.

Frequency can be counted with the aid of special mechanical or electromagnetic counters,[13] or by hand tally. Hand tallying with the aid of a stop watch, has been used, in observing behavior by recording who does what, with whom, when, where, under what conditions and for how long - all these variables being noted on card forms by means of codes, symbols, positioning and shorthand.[9] Hand tallying obliges one to use arbitrary time units, even though these may be of short duration; units as short as three seconds have been used along with hand tallying.[11]

Once the distribution of the frequency and duration of the event has been recorded and computed it is often necessary to re-group and interpret the results in terms of certain indices.

2.3 The Problem of Interpretation

Interpretive indices may be independent of the time record. They may depend on practical and theoretical considerations in the analysis of the subject matter analysed.

According to his interaction theory of personality, for example, Chapple interprets total durations of interruption minus the silences as an index of adjustment.[13] Flanders, on the other hand, interprets his data in terms of interaction matrices.[3]

Such indices, matrices and other numerical interpretations permit one to classify events and their participants into functional categories.

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2.4 The Problem of Categorization

Categories often depend on correlation with other phenomena outside the event in question. For example, it may have been discovered through experience or experimentation that peor .t lominant personalities make poor servants but good masters, or that teachers whose lesson matrices show a lot of student initiative are successful at teaching certain subjects to certain age-groups. The activity of such teachers could be put into the category of 'indirect teaching'[3]. Similarly by using personality indices, persons may be classed as good sales types, supervisor types --- or even neurotics.

The technology of visual and sound recording has become advanced and widespread enough to make the recording of all sorts of events practicable. Later analysis, interpretation and categorization of the components of such event lepends on the purpose, function and state of knowledge and experimentation of the field observed. Computation of time variables, however, depends on advances in instrumentation. This is the aspect of the problem to which we shall now give our attention.

3. Instrumentation

One might say that the history of instrumentation in this field begins with the invention of the stop watch, which was and still is widely used in time-and-motion studies and in games of competition. In fact this is what many people interested in chronometric variables, including the writer, sarted using, until it became evident that such a simple instrument could not meet the complex requirements in the analysis of multiple time variables in [illegible]av[illegible]or.

In the mid-1930s, Eliot D. Chapple, who was then developing his interaction theory of personality, was faced with the problem of measuring the dynamics of personal relations; and he attempted to do so through a study of the duration and frequency of personal contacts, changes in which, he noted, were always associated with expressions of changes in emotion and attitude. Using a simple stop watch, he recorded the duration of contacts in interviews between pairs of individuals and plotted the results on paper having ruled divisions, each equivalent to one minute.

Some time later, this procedure, which was burdensome, limited and imprecise, was replaced by the use of a recording device invented for the purpose. This machine included a paper tape, made to advance at a steady rate of speed, on which a stylus drew a line each time a key was pressed. With one such device per person it was possible to obtain a graphic record of his total talking time (by adding the lengths of the lines), the number of times he started or stopped talking (by counting the beginnings or ends of the lines) and the length of his silences (by counting and measuring the intervening spaces between the lines). The analysis of all this was time consuming; about fifteen hours were required to analyse an interview of a half minute.

In the early 1940s, Chapple perfected a machine which would do most of the computing automatically. It was the first in a series of what became known as "Interaction Chronographs". On these interviews were recorded by an observer using two keys; a computer, sometimes in a separate room, aided in producing a series of graphs at the end of the interview. After several years of use, however, more variables were needed in research than the first Chronograph could measure. A perfected model was therefore developed by the inventor in the late 1940s. In this model, the observer's box was equipped with push buttons, two of which turned the recording machine on or off, two were allotted to the participants (one for the interviewer and the other for the interviewee) and another button activated a counter. After turning on this counter and the two power buttons, the observer kept one finger on the interviewer button and another finger on the interviewee button, pressing down or releasing when the subjects started or stopped talking. At the same time, a computer calculated the relative frequency and direction of the talking. The computer was designed to supply ten different measures by combining the frequency and duration of the stretches of speech and silences of the two persons. The first two measures (in the first two columns) gave the number of exchanges for each person by adding one unit each time one of the two interview buttons was pressed. Two columns indicated the number of times one of the persons had interrupted the other; two columns gave totals for the duration of the interruptions of each party, by subtracting the failures to respond; one column gave total speech or activity time of the interviewee; another added this to his silences, another gave the frequency of the silences (both buttons up), and finally a column indicated the frequency of the interruptions (both buttons down).

Each of these measures was given a certain interpretation. For example, duration of a person's speech (or action) became his activity index. The number of times he came out talking after an interruption became his dominance index.[14]

Although used widely for the analysis of interviews, it must be pointed out that the Interaction Chronograph, in the final analysis, dealt with only two first-order variables -- activity and non-activity. Only two people were dealt with at time -- the interviewer and the interviewee. The process was too complicated for some simpler purposes, the recording was not automatic, and observer's reaction time and fatigue were sources of error.

In 1949, an attempt was made to eliminate the human observer of the interview -- and at the same time reduce human error -- by designing an automatic interaction analyser to record and compute the speech activity of an individual. The speech was first recorded by individual microphones -- one for each person. Each microphone fed a separate tape recorder and computer. Duration and frequency was computed in intervals of 30 seconds; a counter and totaliser of duration gave the frequency distribution in these 30-second units, and finally there was a counter and classifier of interruptions. The apparatus consisted of electromagnetic counters, time delay relays, a stepping switch, and a pulse timer.[10] Although the machine was used in the field of psychiatry, for studies of free association, it was not universally applicable. The 30-second unit was arbitrary and too long for some studies, and a separate machine was needed for each person involved in an event.

In the 1950s a number of automatic devices came out for specific and limited operations in speech analysis. Some were designed only for the study of verbal activity during an interview[4]. Others were invented for measuring rates of speech[15] and variables in verbal conditioning[16].

In 1960, Starkweather conceived a speech-rate meter for verbal behavioral analysis. It produced a graphic cumulative record of pulses of speech,which showed a high correlation with the results of word frequency counts obtained through typescripts[12].

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These counters of speech units are to be distinguished from other automatic speech analysers developed for phonetic research and language instruction, which go back to Homer Dudley's vocoder of the year 1928. The Bell Acoustic Spectograph was developed in the 1940s to make speech 'visible'[17]; this later bacame the Kay Sonograph a version of which was used in the study of voiceprinting, each person having his characteristic print, presumably as inalterable as his fingerprints. These, along with the Mingograph, and the Eric developed by Lucien LeBourhis at Laval, were all used for the purpose of breaking down sound into its acoustic components.

Also in another category are more than a dozen types of speech recognition devices, like the SAID[18] developed under Harlan Lane in the mid-1960s to monitor practice in the learning of the intonation and rhythm of a foreign language. Here students record their speech on tape and look at a meter which displays the degree of acceptability of their utterance as far as the rhythm and intonation are concerned, after which the student re-shapes his intonation to come closer to the model he is imitating. Another, more elaborate device also using a small computer, analyses and recomposes an intonation curve on a television screen; it was developed by Pierre Léon in the late 1960s at the University of Toronto to permit students to compare their tone curve with the model.

By the mid-1960s researchers were still working to improve on the Interaction Chronograph. In 1965, a description was published of a new device called the Interaction Recorder which consisted of a timer and a punch unit. The data recorded was the same as that of the Interaction Chronograph; but it permitted faster processing of these data. It recorded on punched paper tape the sequences of interview speech and silence, keeping a record of when one or the other, both or neither of the persons was speaking. The tape was then fed into a Burroughs E101 computer which was programmed to produce a unit-by-unit analysis of the speech, silences and interruptions of the interview[19].

All these interaction recording devices have a great deal in common:

1. They deal with only three possibilities: activity, no activity or no types. 2. The activity or non-activity of only two persons is analysed. 3. From these two first-order measures, other second and third-order measures are derived. 4. They have narrow applicability, designed as they are mostly for interviews.

If other, more complex materials -- lessons, games, television programs and motion picture films -- are to be analysed, what is needed is a device that will record and compute variables in several types of activity and speech that can be used to analyse the simultaneous interaction of sereral people, a device that will give a greater number of first-order measures while being flexible and adaptable to different kinds of phenomena. This is what we have attempted to do in developing the Polychronometer.

4. The Polychronometer

It was with a view to meeting the needs for wider ranging instrumentation in the analysis of time variables in behavior that the Polychronometer was developed. In the context of what has been done in this field, it will now be easier to understand the history and development of this instrument, its design, mechanism, uses and special techniques.

4.1 History and Development

The development of the Polychronometer began in the mid-1960s when the present writer attempted to relate teacher performance to method analysis[20]. The analysis of the teaching materials having been quantified[21], it was necessary to find a way of quantifying their use in teaching performance. After attempting to use chronometric techniques available at the time, -- all unsatisfactory -- it was decided that the best long-term solution was to develop a machine for this and similar purposes. After a number of different designs and different types of instrumentation had been developed, a satisfactory working model was arrived at in late 1969, with the help of the chief technician of Laval University's Phonetics Research Laboratory, Lucien LeBourhis. After minor improvements and a few years of field testing, we are now ready to report on the features, design, mechanism, uses and special techniques of this new device.

4.2 Main Features

The main features of the Polychronometer are the following:

i) It is essentially a set of paired counter-timer units each operated by a separate key (See Plate 1).

ii) There are as many sets as there are fingers to operate them, that is, ten in number.

iii) This permits the analyst to make as many as twenty first-order measurements in a single run.

iv) Each key controls two types of measurement -- duration and frequency.

v) Duration is measured in real time, since the electronic switches respond as quickly as an operator's reflexes.

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vi) Each set is adaptable to automatic input (like speech recognition devices) or to computer output for first, second and third order measurement.

vii) The machine is light in weigh: .nd easily portable.

viii) Since the key board is separate from the control box the machine can be operated at a distance or by remote control.

4.3 Design

The ten sets of timer-counters are imbedded in a sloped control box (18 x 12 x 6) containing the circuits and driving mechanism along with an on-off switch (See Plate 2). The key board, with two sets of five concave keys, each designed for the varying length and shape of the fingers of each hand, is a separate unit which can be plugged into the control box at a distance. An optional remote control unit can operate videotape or magnetic tape playback machines for the analysis of recorded materials (See Plate 3).

4.4 Mechanism

The mechanical problem in developing the machine was essentially one of circuitry and the coupling of appropriate relays to the activator keys (See Figure 1).

The electronic operation is briefly as follows:

1. When one of the keys is touched, an activator establishes a + HT on a corresponding relay.
    - 1.1 The returning current passes through Q3 and R3, while Q3 remains active. (Base Q3 thru R3 and R4 to the HT, Q1 at rest.)
    - 1.2 Contact S1 auto starts the relay.
    - 1.3 Contact S2 discharges C2 on Base Q6 thru R1, which moves the corresponding key-touch counter ahead one unit, thru Q6.

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1.4 Contact S3 starts the corresponding timer.

1.5 The tension developed by the Q3 emitter is not sufficient to start the monostable Q1-Q2, but sufficient to give to the base of Q5, thru R7, enough current to light the pilot light L1, indicating that one of the timers is active.

2. When another key is touched, its returning current, coupled with that of the previous one, produces enough tension thru R3 at Point C (1 volt) to start the monostable Q1-Q2, cutting the basic current Q3 (10 milliseconds). This unswitches the preceding relay while automatically putting a new relay into action behind the key which has just been touched. Anything over 10 milliseconds will thus be registered. The cycle is then repeated.

3. The stop button switches off all active relays. It must be pressed immediately after the end of the period of analysis. Otherwise, the timer set in motion by the last key will keep on counting.

5. Uses

The Polychronometer can be used for the quantitative analysis of any phenomenon that takes place in time. It can measure the frequency and duration of ten categories -- according to such criteria as place, person, object, organism, sound, action or speech -- while the event is taking place, or after the event through a visual and/or sound recording of it.

If more than ten categories have to be accounted for, it is necessary to use a recording of the event on film, videotape or magnetic sound tape. The categories can be divided into sets of ten, and as many re-runs made as required. For a thorough analysis of what can take place in a classroom lesson, for example, as many as three re-runs can be used.

6. Techniques

Any special techniques needed for the efficient use of the Polychronometer can be mastered in a few hours of practice. Efficiency of use can be increased if the tendencies of the observer-operator and some basic psychological truths are taken into account. Here are a few suggestions:

Divide the categories, if possible, according to a basic dichotomy (e.g. teacher-class, interviewer-interviewee, action-speech, left side-right side, etc.). One side of the dichotomy can be allotted to the right hand and the other to the left hand key board. Allot the most frequent or likely categories to the index and middle finger (e.g. teacher talk). Avoid, if possible, the allocation of similar categories to adjacent keys. Techniques of usage have to be adapted to the type of material being observed and to the aims of the analysis. It would take too much space here to describe all the ways the machine has been used and the results obtained in the first three years. This will be left for a separate article[22]. So will the special types of observation, computation, interpretation and categorization (See above).

Summary and Abstract

There is a growing need for instrumentation which can enable us to observe and compute phenomena that take place in time. Although problems of observation, computation, interpretation and categorization vary from field to field and from problem to problem, it is

possible to design an instrument for use in any situation where time-variables have to be measured as duration and frequency. The Polychronometer is suggested for such purposes. It is essentially composed of ten paired counter-timer sets each operated by a separate key. The ten keys are set in a keyboard which is plugged into the control box, each key being designed for a different finger of the left or right hand. A few hours of practice is sufficient to give an observer proficiency in operating the key board , sufficient to adapt to the rapidity of moving events. Further work is being done to develop different polychronometric techniques for the analysis of behavior.

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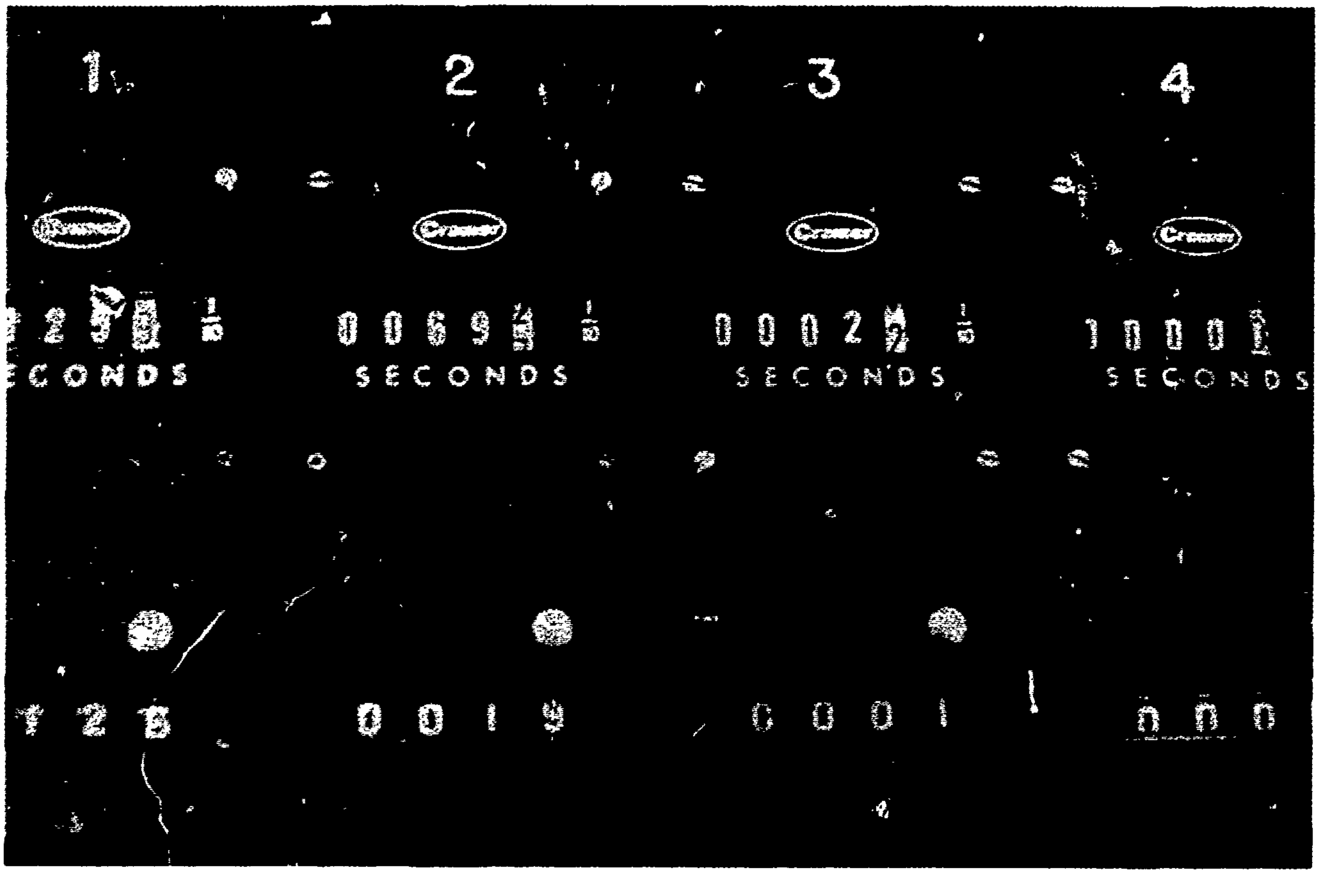
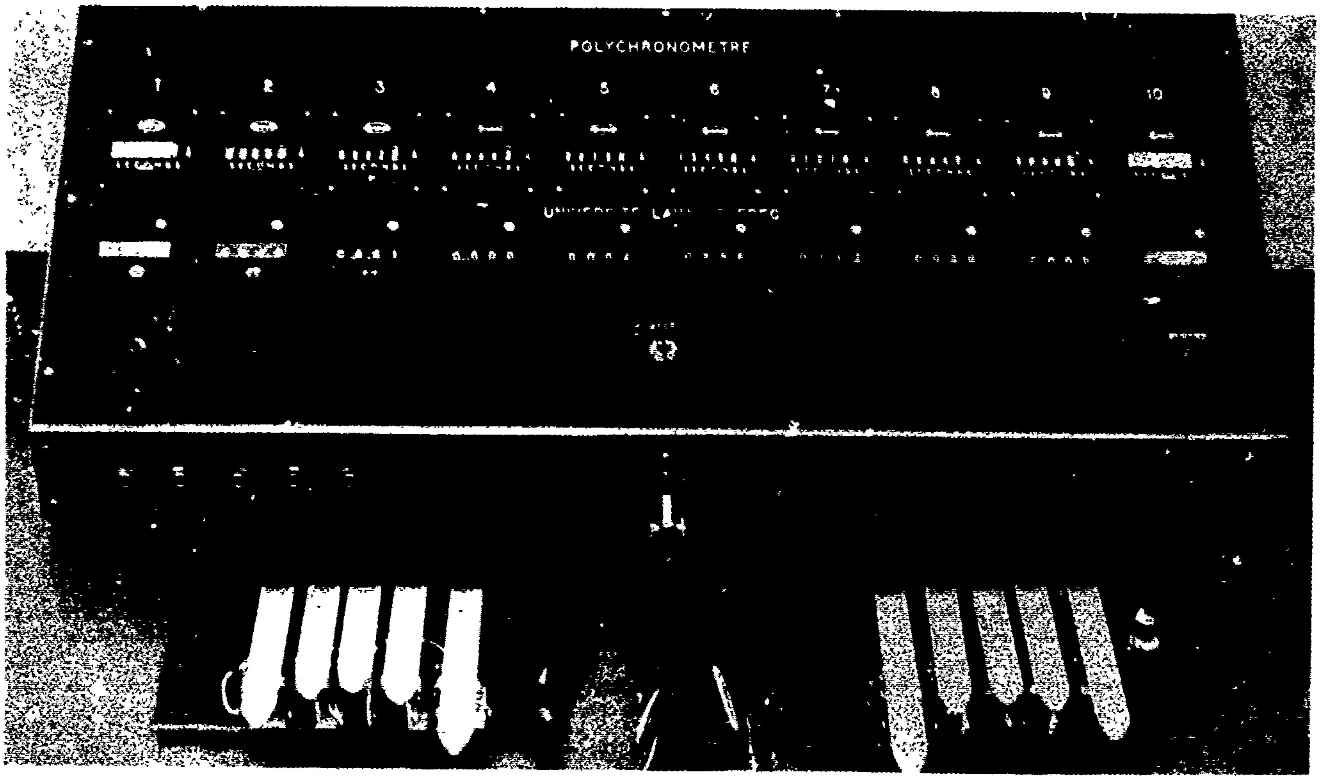
PLATE I



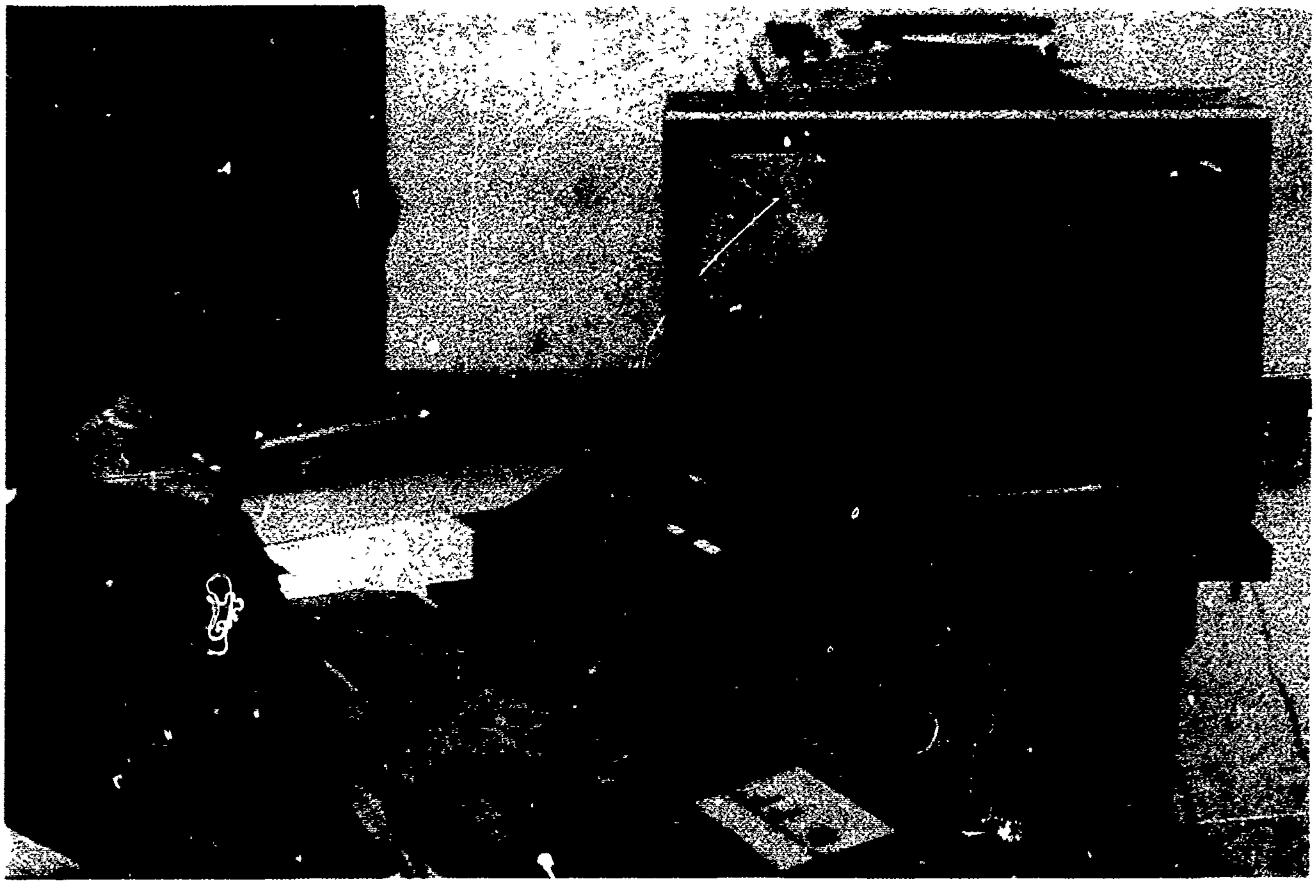
Electronic Counters and Timers

PLATE II



Base with Keyboard

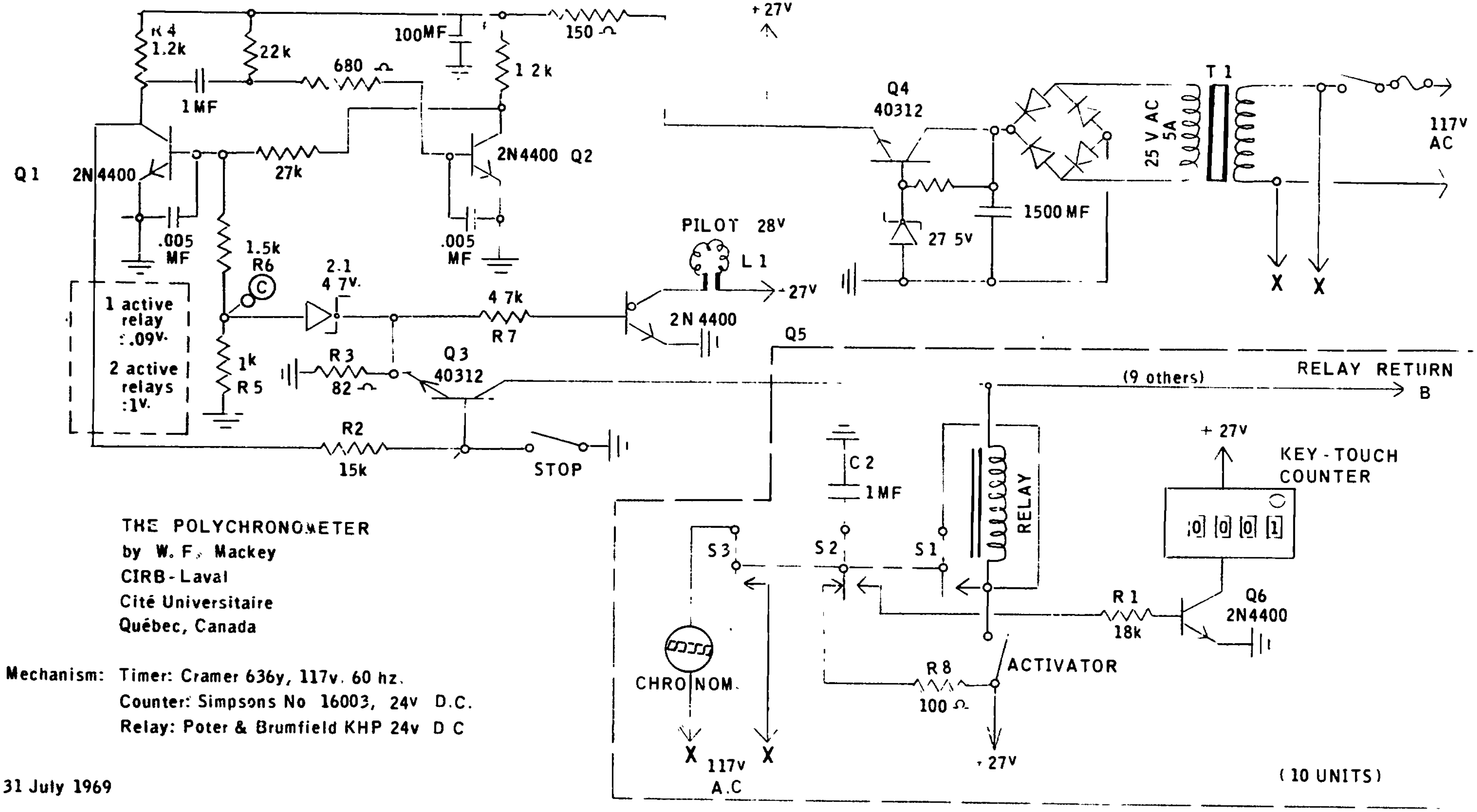
PLATE III



Operation with Remote Controlled Videotape

THE POLYCHRONOMETER

by W F Mackey



THE POLYCHRONOMETER
by W. F. Mackey
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Mechanism: Timer: Cramer 636y, 117v. 60 hz.
Counter: Simpsons No 16003, 24v D.C.
Relay: Poter & Brumfield KHP 24v D C

31 July 1969