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THE DESIGN AND EVALUATION OF A TIMER FOR MOTION AND TIME STUDY RESEARCH

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THE DESIGN AND EVALUATION OF A TIMER FOR

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ABSTRACT

The first objective of this study was to investigate available timing devices and determine if any were suitable for motion and time study research. Six criteria were set up for such a timer:

1. Have a low initial and operational cost
2. Read in direct time
3. Have an accuracy of .0001 minutes
4. Have provisions for automatic multiple timing
5. Retain a permanent record
6. Have a range of at least thirty minutes

The Thusen timer more nearly met the criteria than any timer in existance; however, the initial cost was high and the timer did not read in direct times. Since no timers were found which fulfilled these criteria, a second objective, the design of a suitable timer was established.

The new timer reduced the initial cost of the device, substantially reduced the size compared to the Thusen timer, and facilitated easier subtraction of times. This timer was not completely built and tested; however, it was evaluated by components and seems to more nearly meet the above criteria than any other timer in

existence.

It is recommended that the timer be completed and tested in order to determine its capabilities and limitations. Also, this should be done in order that redesign and development can be continued.

CHAPTER I

INTRODUCTION

History

The measurement of time has a history dating from about three thousand years before Christ. It was at this time that in all probability the first crude devices were used to measure an interval of time. Even then there was a definite need to measure, control and regulate amounts of work. Devices for measuring time controlled the amount of water-flow in the irrigation of fields, aided in the navigation of ships, and became a measure of work accomplishment. Prior to this time people roughly measured the amount of work in terms of days, months and even years. As time progressed and people's skill became greater, they accomplished similar tasks in shorter periods of time. As a result of this, there came a need for measuring work accomplishment in units of time smaller than a day. Since that time, many devices have been developed, all of which do not appear to be satisfactory for the measurement of work. It is this measurement of work and the reduction of work which primarily determines the objective of this thesis.

Statement of Objective

It is the object of this thesis to investigate the available timers and determine if there are any suitable for motion and time study research, since the timers used at present do not appear to have the attributes necessary for motion and time study research. This could be due to one of two reasons:

(1) The timer is known, but full advantage of its capabilities are not recognized nor utilized for motion and time study research, or

(2) There is no timer developed for motion and time study that will produce the desired results for research.

If it is found that there is no timer suitable for motion and time study research, it will be necessary to design and construct a machine that will meet as many of the requirements as is practical.

Why the Problem Exists

It would facilitate a better understanding of motion and time study research to cite an example of each to demonstrate the procedure and evaluation techniques used in them. These examples are not intended to be complete or full explanations of all the methods or procedures followed; however, they are intended to demonstrate the need and convenience of having a suitable timer.

Motion Study.--Motion study research involves the use of an accurate time machine so that small elemental differences in motions can be recognized by an analyst. For example, an observer wishes to see which pattern of movement is best, and desires to test the difference between moving a pin to three points not on a straight line by a circular and by a straight path. This may be accomplished by designing a circular path where the three points are on the circumference of the circle, and by moving the hand in a straight line from one point to the other so as to describe a triangle. This does not include all of the possibilities; however, it will show the use of a timer for motion study. To continue, the analyst desires to determine which of these two motion patterns is the better. He would arrange the points in a triangular shape and fix two paths, one circular and the other triangular. He would then direct the subject to perform the experiment in a prescribed, acceptable manner. The analyst would time enough of the patterns to be reasonably sure he had representative time values. Then he would compare the obtained time values to see whether his hypothesis as to which motion was the better is true. He would evaluate this by comparing the times of the two. The motion with shorter time would be the better one for accomplishing work.

The stage of development in motion study is now at a point where the time differences that have to be distinguished are comparatively small, and a large number of readings are required to obtain reliable results. Motion study research is handicapped by the lack of a timer that is of sufficient accuracy and that will facilitate a large number of readings at a reasonable expenditure of time and money. However, before more elaboration of the problem of timing is continued, an example of time study research is given.

Time Study.--The example to be used is a problem involved in determining the elemental time for a motion. This requires some insight into how the particular variables involved are controlled, minimized, or eliminated. Then some of the importance of the problem of obtaining a special timer can be appreciated. For this example, the determination of a synthetic time study shall be followed through.

It is first necessary to have a more specific understanding of synthetic time study. Essentially synthetic time study is a form of standard data gathered by either the laboratory or the shop with meticulous care as to the selection of the basic motions. By this procedure a pattern is set up in which the analyst hopes to encompass all basic motions so that with any given job, the element or motion time can be determined from tables without additional timing. A careful analysis of the basic times requires the separation and recording of each type of motion and the classifying as to some type of restriction. This can be shown by simple demonstration. Let us assume for the moment that a movement of the forearm in a horizontal plane without any perceptible movement of the other members of the body is a basic motion. There are several types of restrictions to this movement such as distance, weight, and control of start and stop. It would be next to impossible to determine and evaluate all of these restrictions; therefore, the next best thing to do is to minimize or to take only those which show the highest degree of correlation. This is the normal practice in establishing synthetic time studies, but it introduces errors because without all the variables an exact solution is not possible except through chance. The synthetic systems try to approach the exact, or what is believed to be exact, by controlling as many of the variables as can be determined. However, the problem comes in controlling or eliminating these variables.

With the use of timers now available for this type of work, researchers are handicapped as the magnitude of the number of readings that have to be taken in order to arrive at reliable time values, which limits to some extent the type of motions that are timed.

In the development of standard data, predetermined time study data and basic motion study principles, it is necessary to procure a large enough number of sample of time values for a given motion to be reasonably sure that it is representative of the time required to perform the task. A timing device must be accurate and precise enough to distinguish between small basic movement times which are usually encountered with movement of the hands and arms.[1]

Another important factor that must be taken into consideration is the amount of researcher's time employed in actual reading or interpretation of the time values obtained.

As the amount of researcher's time limits to a great extent the amount of data that a man can amass, it limits the results he can produce. Without this data the researcher is limited to investigations that require the fewest number of readings to be reliable and the type of studies in which he can distinguish a difference in time values. The cost of amassing large amounts of data becomes a problem that few individuals or organizations can afford.

Still another type of difficulty arises in the case where one motion is restricted or dependent on the preceding or succeeding motion. These preceding or succeeding motions must be timed at the same time as the primary motion, otherwise no reliable conclusion about the motion can be obtained.

There have been several attempts to eliminate these difficulties involved in motion and time study research. These attempts are chiefly along two lines. One is in the better design of experiments so that less time is required to perform and evaluate the experiment. The other is the building and operation of better timers (that is better with

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[1]Ralph M. Barnes and E. D. Williams, Jr., "The Automatic Time Recorder," Modern Management, V. 9, M '49, p. 4.

respect to time and motion study). This separation of the two phases is not intended to give the notion that they work independently, for they work together.

Some of the attempts to alleviate the timing problem are the Kymograph, the motion picture camera, the Thusen timer, and the stop watch. Other devices are employed, but these four are representative, as well as being the most commonly used.

The Kymograph is a very accurate timer. It can time more than one cycle, thereby allowing several occurrences to be timed simultaneously. However, its cost of operation is high due to the method of interpolating the data from a scribed line.

Motion pictures are used for research work in motion and time study; however, as the number of readings becomes great and the accuracy requirements fall in the range of .0001 minutes the use of film becomes expensive. This is due to the amount of film needed to obtain reliable results. The use of motion pictures has several disadvantages; the high cost of operation, the amount of time required to set up an experiment, and the inability to analyze the data obtained (the difficulty in analyzing the data lies in recognizing the beginning and ending points of the elements).

The Thusen timer alleviated the high operational cost by the use of printing wheels, thereby facilitating easy interpolation. This was gained at the expense of high initial cost which makes it unavailable to most institutions. It does not read direct time, but accumulative times. It requires an operator to subtract the successive elements to obtain direct times.

The stop watch is in the low priced range and is probably the most used device for that reason. It has many objections in its application to time and motion study research. These are: one, the accuracy is not sufficient, as the values now needed are approximately .0001 minutes; two, there is no permanent record (which is desirable if the results have to be checked); three, it only times one cycle or element at a time (which is not desirable for motion and time study research because it is desirable to set up multiple element experiments).

The operating principles of the above devices will be discussed further in Chapter II.

From looking at some of the disadvantages of the timers in use for motion and time study and the nature of the work, the needs of motion and time study research can be obtained. The factors that enter into a timer for research are:

(1) The timer should have a reasonable initial cost so that it may readily be afforded by individuals and institutions desirous of carrying on motion and time study research.

(2) The timer should be low in operational cost so that an individual or institution could afford the quantity of studies required to obtain reliable results.

(3) The timer should time more than one element or cycle so that studies where one element is dependent on another can be timed successfully and so that multiple element studies can be designed in which an economy of experiments and time is obtained.

(4) The timer should record the times so that there is a permanent record. This is desirable since the values may then be checked without the additional time of running a duplicate experiment.

(5) The timer should at least obtain the accuracy of the Thusen timer (.0001 minutes), as the latter has proved

satisfactory for research purposes.

(6) The timer should time direct values so that no additional work is required to obtain the desired results.

(7) The timer should have a comparatively long range of times so that the long elements can be timed without the use of additional equipment.

(8) The machine should have provisions for automatic operation, so that the analyst can give his full attention to observation of the performance, and so that his reaction time will not be a variable in the experiment.

(9) The device should be easy to set up and operate so that the researcher's time is not spent on the details and routine work necessary to make a study and so that a technician will not need excessive training in this operation of the device.

The forementioned points or requirements for motion and time study research allows the development of criteria on which to evaluate and build, if necessary, a timer for research. These criteria are given below.

Criteria

A timer for motion and time study research should meet the following requirements:

(1) Have low initial and operational cost.

(2) Read in direct time.

(3) Have an accuracy of .0001 minutes.

(4) Have provisions for automatic, multiple timing.

(5) Retain a permanent record.

(6) Have a range of at least thirty minutes.

How the Study Is To Be Approached

The foregoing has given some insight as to how the problem shall be attacked; however, as the problem could very possible lead into several different phases, it is necessary to describe the method of treatment used in order to get a solution to the problem.

In light of this statement it will be necessary to enumerate the steps in the solution of the problem. These are:

(1) Review characteristics of motion and time study research relative to time evaluation (what has been used, how good a job was done by it, shortcomings, etc.)

(2) Establish criteria for an ideal research timer.

(3) Review the literature to see if any timers are available that will meet the needs of motion and time study research.

(4) Evaluate the existing time recorders according to their suitability to motion and time study research in terms of the criteria.

(5) Assuming no suitable timer is available, design a timer suitable for motion and time study research. This will include a set of drawings.

(6) Build the device in order to get a final evaluation of the capabilities of the timer.

(7) Test the timer, if it is necessary to build one (therefore, it will be necessary to design an experiment to test the capabilities of the timer).

(8) Evaluate the timer, if built, from the experimental test results obtained.

(9) Explain the operation of the timer in terms of its limitations so that it can be effectively evaluated by the eventual user, effectively utilized for motion and time study research, and further developed at some later date.

As can be seen, the first two steps are already completed. Chapter II covers steps 3 and 4. Chapter III will cover steps 5 through 9.

CHAPTER II

A CRITICAL REVIEW OF TIMERS

History

As a brief insight into some of the early works of man in his attempt to solve the forementioned problems, this thesis will go back to some three thousand years before Christ and view some of the devices that were used then to measure a period time. These devices were some of the first, and although they were excellent attempts to solve the problems which were discussed at the beginning of this thesis they lack the precision and accuracy needed today, although they add background in man's attempt to measure time. Some of these devices were:

(1) The water clock, which operated on the principle of fluid flow through an orifice. The time for a given amount of water which would flow into a vessel was regarded as a constant. This resulted in a time unit.

(2) Graduated candles, which operated on the principle that a given size, constant consistency and uniform material will burn the same number of inches in a given unit of time. The candles were later graduated to give continuous time without the care of an operator.

(3) The hour glass, which operated on the principle that a given quantity of sand would pass through an opening in a glass in a constant interval of time.

(4) The sun dial, which operates on the principle of the constant rotation of the earth with respect to the sun. The sun moves across the sky and casts a shadow from a pointer to a calibrated face which results in a time value.

(5) Calendars, which again operate on the principle of the constant movement of the earth with respect to the sun. However, this type differs in that it measures

days instead of hours and minutes.

For obvious reasons, these and similar devices lacked the precision and accuracy needed today.

It was not until the sixteenth century that a mechanical means, a series of wooded gears with a source of potential energy, for measuring time was developed. The accuracy and precision of these timing devices were limited to hours, minutes and seconds. This was due to non-uniform materials and lack of precision in the manufacture and fabrication of materials and parts. There was a slight increase in precision but it was not until the nineteenth century that any substantial improvement was shown. These devices are the forerunners of those used today.

Today we have many devices that will meet the needs of many specific timing jobs, some of which require extreme accuracy and some which require good range. These do not seem to meet the need with which this thesis is concerned; however, a discussion of the various devices would help in finding one that would meet the need for motion and time study research.

In order to accomplish this purpose, the third and fourth steps involve the reviewing of literature on existing timers and an evaluation of that literature. For the sake of convenience the existing timers can be classified into two main categories and then subdivided further. This breakdown will include devices that are in existence and those that can be conceived from existing mechanisms. With the classification, a clearer picture of which devices will meet the criteria can be obtained.

The two major divisions will be according to use of the data.

Data from the machines can either be in a form that facilitates direct use, that is to say the material is in a usable form without any modification such as subtracting or measuring, or it can be in a form that requires further work to obtain the desired time values. This second type shall be called interpolated, thereby meaning the subtraction or measuring in order to obtain a time value.

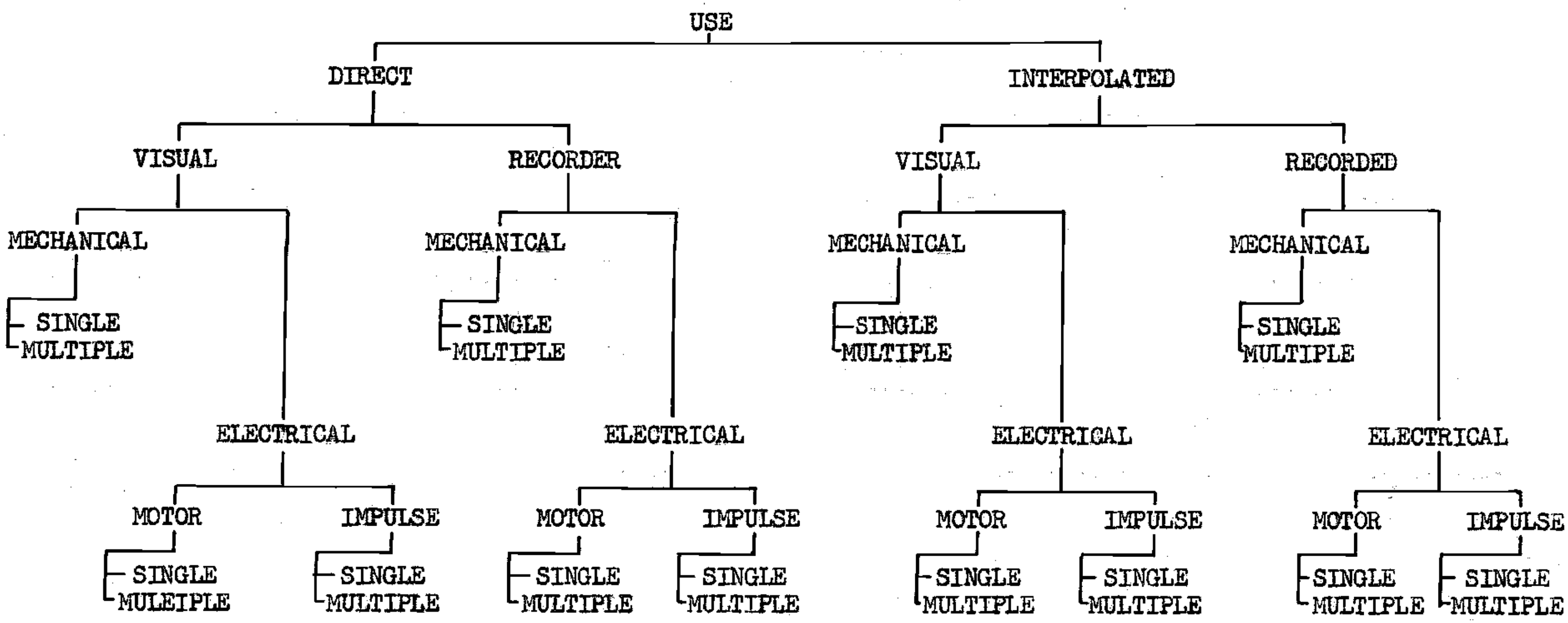
These types can further be subdivided into visual and recording. In the visual type, an operator must visually look at and manually record the data. In the recording type, the machine actually records the data on some type of material making a permanent record.

Again, these can be subdivided into classifications of mechanical and electrical. This is the subclassification that divides the power source. Electrical can further be broken into impulse and motor. Impulse refers to a charge of electricity being counted or stored. The motor type can be either synchronous or non-synchronous. The non-synchronous, however, does not have sufficient stability to be used in precision timing devices.

The classification will be carried one phase further, that is, to single or multiple element times, the single element timing only one element and the multiple timing two or more elements. This complete breakdown is shown best in the form of a diagram (See Figure 1.).

Direct Timing

First, direct timing methods will be approached. "Direct," as mentioned before, will mean that the reading is in a usable form requiring no subtraction or interpolation of any form. Under this


USE
DIRECT
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SINGLE
MULTIPLE
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MULTIPLE

Figure 1.

classification the first type of device is visual, meaning that the record must be made manually and in a usable form. There are, as the classification continues, either mechanical or electrical types. Mechanical shall be discussed first.

Mechanical mechanisms derive their power from a spring, which in turn releases its power to a series of gears through some type of an escapement or governor. These two governing mechanisms release the power at a constant rate, therby giving the mechanism a movement proportional to time. The gears drive either hands, which are read from a graduated dial to indicate time or to a set of type wheels, which print a time value on paper by the sue of a striker mechanism. Some supplementary mechanisms which will aid in obtaining accuracy will be considered. A device of this type is a solenoid. The stop watch, the watch, and the clock fall in the direct visual mechanical classification. To fall in this classification they must be used by a snap-back method of timing. The snap-back refers to a method whereby the timing piece is returned to a normal or zero position after a timing cycle and started again for each new cycle. This results in a direct visual mechanical single element time.

A variation of the above method is to bank several stop watches, watches or clocks together and to alternate the timing from one device to the next. This produces a result of timing more than one element.

The stop watch is a spring wound mechanism in which potential energy is released through a regulating mechanism. The regulating mechanism is usually an escapement which uses a balance wheel for the governing period. The period of the balance wheel is the governing or regulating force for the entire mechanism. The best quality stop watches contain a balance wheel which is compensated for temperature variation by the use of two dissimilar metals--dissimilar by virtue of their expansion coefficient--in the periphery of the wheel. As the temperature rises, the diameter of the wheel decreases, thereby having the effect of pulling the mass nearer to the center of the wheel. This reduces the inertia of the wheel, which enables the hair spring to propel the balance wheel at the same period, facilitating temperature compensation. This method is not perfect as the watch can only be compensated for two temperatures. These are usually 45 and 90 degrees Fahrenheit.[2] The most common method of starting the stop watch is to remove a pawl from the escapement which allows the mechanism to run without impediment. The stopping of the watch is accomplished by replacing the pawl, which impedes the movement of the mechanism. Other than the governing and stopping function of the escapement mechanism, it permits power to be released through a system of gears which drive a hand or hands on the face of the watch. The face is the point at which the watch is read to obtain time values.

The stop watch is very portable, as it is small in construction and can be carried from one place to another without difficulty. The operation of the stop watch consists of occasionally winding, pressing of button and reading of the watch. For more accurate application of the stop watch an electromechanical means is occasionally employed to depress the start and stop button. The electromechanism consists of a

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[2] A. Lockhart, "A Survey of Devices Used in Measuring Short Time Intervals," American Association Health Physical Education and Recreation, V. Q12, Dec. '41, p. 763.

solenoid operated by electrical contacts or a photoelectric cell. When the tenth of a second stop watch is operated in this manner its potential accuracy of .0016 minutes is closely realized.[3]

The stop watch, being a device which does not have provisions for recording the time, must have an operator present to visually look at and manually record the time values obtained. It is because of an operator reading and recording time values from a stop watch that some of its main disadvantages arise.[4] The data is read by a visual means and there are errors in the reading and recording of the data. In the use of such an instrument for the purposes of motion and time study research, it would be limited to hand operation as the elements must be taken in rapid succession.

The cost of such an instrument is comparatively low.* It is inexpensive enough for institutions and manufacturers to purchase for production studies and limited, in terms of accuracy, research purposes.

Watches are a mechanical timing device using as a source of power a spring similar to the stop watch. Watches are usually calibrated in seconds, minutes and hours. They are again read directly from a calibrated dial. The position of the hands is used to indicate time values.

Watches are seldom used in research except in the case of

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[3] Ibid., p. 763.

[4] I. P. Lazarus, "The Nature of Stop Watch Time Study Errors," Advanced Management, V. 15, May '50, p. 15.

*Stop watches can be obtained for approximately $20 to $350.

extremely long element times, for as the element times increase in length the percentage of error decreases.

The clock is essentially the same as a watch. It is usually considered a larger model. For this reason there is no necessity for discussing it further.

These devices do not meet the criteria for a timer for motion and time study research. They fail in two respects. These are:

(1) The timer should have a permanent record.

(2) The timer should read to .0001 of a minute.

The other factors of the criteria that these devices fail to meet could be obtained without excessive difficulty.

In the direct visual classification of timers the electrical timers will be discussed next. There are essentially two subclassifications for this type of timer, the impulse and the motor.

Direct visual electrical impulse.--The direct visual electrical impulse single element timers are designed on the capacitor leak principle, the capicator charge principle, and the frequency generator with a decade counter principle.

In the capacitor leak a condenser is charged by a constant voltage and is allowed to discharge. The rate of discharge can be calculated (from the difference in potential) very accurately in terms of time. Usually a vacuum tube voltmeter is used to measure the difference in potential. The voltmeter can be scaled in units of time, eliminating the necessity for the conversion of volts to time. These units have a range of .00001 minutes to several days, and have been known to measure as long as two weeks.[5] On the larger ranges there has to be a switching of scales so that the deflection of the indicator on the voltmeter is readable.

In the operation of this device the analyst has to read the voltage or time at the end of the element timed, and charge the capacitor for the next element. For cycles of short duration some means has to be provided so that additional discharge, due to the resistance of the voltmeter and natural discharge of the condenser, does not occur. If this does occur, the short element time values will have a considerable percentage of error.

The voltmeter is read visually by an operator. His skill determines the accuracy and validity of the readings. As in the stop watch, the device is subject to the same difficulties of inaccurate recording.

These devices are moderately large, but could be transported from one location to another with comparative ease. From the information available, the charging time of the capacitor is extremely short; however, care must be employed so that the time interval is comparatively short in relation to the timing accuracy.[6]

The capacitor charge is the reverse of the above procedure in that the charge is constantly applied to the condenser. The gained charge is calculable in units of time. This does not appear to have any appreciable advantage over the leak principle.

A frequency generator with a decade counter consists of a

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[5] E. A. Walker, "An Instrument for Measurement of Short Intervals of Time," Franklin Institute Journal, V. 231, April '41, p. 373-9.

[6] Ibid.

frequency generator and an electronic counter. The purpose of the frequency generator is to furnish a constant source of pulses. These pulses are counted by the electronic counter, which is capable of adding up to 1,000,000 pulses per second. The timing is accomplished by the direct use of the pulses, which are allowed to pass in to the counter unit during the timing interval. At the end of the element being timed, the pulses are stopped by an electronic gate which essentially operates as a switch. The time value can be read directly if decimal multiples of a minute are fed from the frequency generator. For example, a generator delivers 10,000 pulses per minute. The unit would read to ten thousandths of a minute. The device is read visually, which allows no permanent record.

These devices do not meet the criteria earlier established, and therefore are found unsuitable for motion and time study research.

(1) They have no permanent record.

(2) They do not time more than one element.

(3) Their range is comparatively short (that is, unless some means is provided to change the scales).

The devices can be made to time more than one element by using more than one unit. For instance, the decade counter can be built up in several units so that it will time any desired number of elements. However, it is not necessary to use several frequency generators as one will suffice for a bank of counters.

This eliminates the objection of not being capable of timing multiple elements, however, the use of multiple units adds another factor in that the initial expense of the unit is excessive.*

The capacitor leak principle could be built up in the same manner in order to obtain multiple elements. It fails to meet the criteria for the same reasons as the decade counter fails.

Direct visual electrical motor.--A device that comes under the direct visual electrical motor classification is the stop clock.

Stop clocks are powered by a synchronous motor, and by virtue of it the timing accuracy is dependent on the source. The revolutions per minute of the motor are dependent on the number of cycles per minute. Therefore, the clock is no more reliable than the source of current. The motor directly drives the hands or a series of gears which drive the hands and the hands are read visually from a calibrated dial. The clocks are stopped in either of two ways; one is to interrupt the source of the current so that the clock stops (of course, in this sytem there is always the undesirable feature of inertia carrying the hands past the desired value), and the other system employs a break, designed to overcome the effects of inertia. The break is operated in connection with the interruption of the current. This stops the arm at the desired point. These two, being essentially the same type of mechanism, will be classed together.[7]

This device fails to meet the criteria in that

(1) It does not have a permanent record.

(2) It only times one element.

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*The estimated cost from components used, for a six-circuit unit, is approximately $1,400.

[7]L. A. Steiner, "On Timing Devices Merrits and Limitations of Three Types," Chemical Age (London), V. 54, April '46, p. 453-7.

This device can be built up of several units and could, therefore, time more than one element; however it still does not meet the criteria in that it does not have a permanent record.

In reviewing the direct recording mechanical single element timers it is found that there are none; however, there are two conceivable timers in this category. One is the use of the stop watch, clock and the watch in combination with a camera, the other the use of these three devices with type wheels. The photographic method would be to time the element and at the end of the element to stop the timing device and photograph it. This however, does not meet the criteria, as

(1) The operation cost is comparatively expensive if many readings are taken.

(2) The accuracy is still not sufficient for motion and time study research.

(3) Only one element is timed. This of course could be overcome by the use of multiple units; however the difficulties of 1 and 2 would still be present. In addition to the above mentioned failures to meet the criteria there is a delay in obtaining the data.

Type wheels could be incorporated with the stop watch, the watch and the clock. This is not very practical as it would not meet the criteria. It would fail, since the accuracy is not sufficient for motion and time study research.

The direct recording electrical impulse type of timer is essentially the same as those under the classification of visual timer except that a photograph, type wheels or a recording voltmeter could be used in conjunction with the devices. The use of the additional mechanisms would make the devices recording.

The type wheels are not practical to use in conjunction with the impulse type of device due to the difficulty in transferring the pulse into a mechanical action from which a recording can be obtained. A mechanism of this nature makes the timer economically impractical from an initial cost.

A photo used in conjunction with the timers would also give a direct recording; however, it would make the operational cost high and it would require a delay before the data could be used.

A recording voltmeter used with the capacitor leak principle shows some promise as it can meet all of the criteria. However, there is one main difficulty that has to be overcome; that is switching the scales so that the accuracy of the device is not seriously impaired. This possibility will be discussed further in Chapter III.

The devices in this classification can be made multiple element by the addition of units as discussed under direct visual electrical multiple elements.

The direct recording electrical motor device such as the stop clock can be made to record time values by either using type wheels, photographs or a scriber in conjunction with it.

The type wheels could be connected to the rotating member of the clock and be made to record time. The difficulty comes in the resetting of the device, just as in the visually operated stop clock. This resetting would be impractical as it would lose time in the reset of close elements and the cost of incorporating a reset would probably double the cost of the clock. A more applicable timing device would be the interpolated recorder discussed later.

A photograph of the timer would result in a permanent record, but it still has the difficulties encountered on the visual timer of the same type with the addition of the delay in obtaining the data. Photographing the clock results in an expenditure of money to obtain the data, and if a large number of readings are taken the cost becomes excessive.

The scriber method can be employed in the conventional manner by replacing the hands of the clock with a stylus. However, this results in shortening the range of time. The range is shortened by the fact that the second rotation of the hands would be retracing the time values and therefore only one rotation would produce a readable result. This device does not meet the criteria as

(1) The range is too short.

(2) The accuracy is reduced due to the scribing of the data.

A German, Professor Poppelreuter,[8] invented a time study machine in 1929 that is a slight modification of the above principle. The machine moves a tape past a scriber at the rate of approximately 3/4" per minute. A pen moves perpendicular to the length of the paper by a constant speed. At the end of the element the pen returns to its normal position and is ready to time again. This had the difficulty of a short range. This time study machine had an accuracy of only .01 minutes and is estimated to a value of .001 minutes. This unit, however, does not meet the criteria in that

(1) It does not have sufficient accuracy.

(2) It does not time more than one element.

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[8] J. Decker, "How Many Hours A Day Do Your Machines Work," Factory and Industrial Management, V. 83, Nov. '32, p. 422-4.

Interpolated Timers

Since direct visual reading timers have been discussed earlier in this chapter and were found to be unsatisfactory as they did not meet the criteria, only the devices that have already been developed will be discussed. The difference in these and those already discussed is that the device is not returned to the zero position after each timing cycle.

In general the timers in this classification do not meet the criteria because

(1) There is no permanent record.

(2) The data is not in a usable form.

Continuous clocks use a synchronous motor for the source or driving mechanism, but they do not have the feature of stopping. In this category falls the wink counter, capable of timing to 1/2,000 of a minute, this unit being called a wink. Of course, they are not limited to this value, but they are not readily obtainable.[9]

Another variation is to photograph continuous clocks. This does not meet the criteria in that the cost of obtaining the results is high and the accuracy is not sufficient.

In this last classification under discussion, the greatest possibilities for developing a timer for motion and time study lie, and within this classification interpolated electrical recording are the most fruitful.

The first device in this classification to be discussed is the

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[9] Lockhart, op. cit.

interpolated recording impulse type. There are four possibilities in this classification. They are printed data, photographed data, scribed data and magnetic data.

The use of type wheels with an impulse type of timer is impractical due to the fact that the voltage has to be increased until it is sufficient to turn a motor or operate a solenoid. The solenoid method does not meet the criteria since it is not able to obtain the accuracy greater than .001 minutes. The first offers no advantage over the motor type mechanism discussed a little later in this classification. The use of a photograph does not meet the criteria as the cost of taking the time values becomes excessive, as they have to be photographed and interpolated.

The scriber method is to use a recording voltmeter with the impulse type of instrument; however, this still has the difficulty presented by the direct reading type of mechanism discussed before with the additional fault of having to be interpolated.

There is another method of recording impulse timers; that is, to impress the pulse on a magnetic tape. The pulses are obtained from a frequency generator. The pulses are fed directly into a magnetic recording head which impresses the pulses on the magnetic tape. The tape is later run back through the recording head and an amplifier increases the pulse. The pulse is counted by a solenoid operating a reciprocating printing counter. At the end of an element the counted number of pulses are recorded on a tape by pressing a striker against the type wheels. This device is capable of timing to 1,000,000 of a second. The device can be built with multiple recording head which will allow the timing of more than one element at a time.

This device fails to meet the criteria in that the initial cost is excessive. There is also a delay in obtaining the time values, as the magnetic tape has to be interpolated.

These units as before can be combined in multiples to use an indexing device so that the elements can be identified; however, further investigation does not seem justified for the reasons mentioned.

The interpolated recording electric motor type of machine has been the most fully developed and investigated type of device. It has also proved the most successful. Devices of this type have been developed along the lines of type wheels and scribed data. The photographic method does not seem to give fruitful results as the cost of photographing and the delay in obtaining the values does not meet the criteria; therefore, previous investigations seem to come to the same conclusion as reached by this writer--that there is not too much practical value in the photographic method.

The type wheel method has been used by Barnes, Thursen, and L. D. Davis. These three men collaborated to build two machines.[10] The device built by these men operated on the principle of using a synchronous motor to drive type wheels. The devices were calibrated in units to .0001 minutes and are capable of recording more than one element. This type of device meets almost all of the requirements for a timer for motion and time study except that the time is not recorded directly and the initial cost of the device is excessive. The author is of the opinion

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[10] Barnes and Williams, op. cit.

that by modifications in design the cost of the device can be very reasonable and the design will be discussed in Chapter III.

Another variation of the synchronous motor timing is a timer developed by Dr. Dale Jones[11] in which he used a magnetic wire recorder and allowed the recording machine to run. He noted the start and stop by a sharp click on the microphone. He later attached a revolution counter to the recorder and transcribed the wire again. The revolutions between clicks are directly convertible into time values. It is claimed by Dr. Jones that the device is accurate to .001 minutes.[12]

The scriber method is used in two timers, the Marstochron and the Kymograph. The Marstochron is a device which derives its power from a synchronous motor that runs a tape with printed numbers already on the tape. The tape is marked at the beginning and at the end of the cycle. The times are subtracted and a time value is obtained. This device does not meet the criteria in that the accuracy is only .001 minutes, the time has to be interpolated and only one element is timed.

The Kymograph is another device which derives its power from a synchronous motor. The only difference is that instead of showing the time on a marked tape the time value is obtained by pulling a tape at a constant velocity and the time is traced by a stylus on the paper.

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[11] Dale Jones, "And Now; Recorded Time Studies Dictated Into Magnetic Wire Recorder," Factory Management and Maintenance, V. 108, March '50, p. 126.

[12] Ibid.

The interruption of the line is measured and converted in order to obtain the values.

A variation is the Marstograph which times six elements; however, the accuracy is not sufficient to meet the criteria.[13]

It also does not meet the criteria in that it is expensive and time consuming to use.

Another method of obtaining recorded data would be to transfer the time value into punched data such as on an IBM card. This would require the use of a card feeding mechanism in order to obtain a card for each time value, a punching mechanism, a coding or timing mechanism and a reading mechanism. The reading mechanism would in all probability be a calculator which would be rented. The other devices would be excessively costly due to the quantity and quality of the needed component parts of the machine. This type of device would be highly desirable for research if the initial cost could be afforded, as this type of data could be programmed on a calculator to statistically analyze the data. Due to the high initial cost the machine fails to meet the criteria.

From the previous discussion it appears that there are two devices which show promise for a timer for motion and time study research. They are the direct recording electrical impulse timer and the interpolated recording electrical motor timer. These will be discussed further in Chapter III to see which facilitates the best timer for motion and time study research.

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[13] "Now Machine Made Time Studies", Factory Management and Maintenance, V. 97, N. 5, May '39, p. 66.

CHAPTER III

DEVELOPMENT OF A NEW TIMER

From the last chapter, it has been seen that there are two devices that warrant more discussion as a research timer. In this chapter the two timers will be discussed and the better of these two shall be considered for additional development. These two timers are the capacitor leak timer and the Thusen timer.

The Capacitor Leak Timer

The first of the timers considered will be the capacitor leak. This timer works on the principle of a constant voltage applied to a condenser. The condenser would be energized until the timing cycle is started. During the timing cycle the charge on the capacitor would be allowed to dissipate through a resistance. The resistance is the load on the capacitor and would of necessity be of high quality so that its value would not change appreciably during the operation of the unit. At the end of the timing cycle the resistance would be removed from the circuit. This serves to stop the discharge of the condenser. The condenser then has a remaining charge proportional to the time elapsed. This charge is read with a vacuum tube voltmeter. It can readily be seen that a vacuum tube voltmeter must be used, as the interval resistance of a standard voltmeter would allow further discharge of the condenser, thereby giving an erroneous reading of time. The cycle is repeated by disconnecting the voltmeter, connecting the resistance and connecting the voltage source. The condenser charges and the, when the timing continues, the voltage source is disconnected and the cycle is repeated.

The timer just described is a direct visual electrical impulse single element timer.

This timer can be made multiple element by the addition of several units. The units would be connected with additional condensers, additional resistances, and additional switches. The volt source would not have to be duplicated, as one unit would be sufficient for the bank of condensers.

The timer has the major difficulty of recording. This could be accomplished by the use of a recording voltmeter. There is a loss in the accuracy in the recording time due to the loss in accuracy of the voltmeter. This inaccuracy is in the neighborhood of ten per cent of the voltage recorded. This, however, would not cause the unit to be inaccurate enough for time values in the neighborhood of one ten thousandths of a minute. The recording voltmeter can be scaled to read time values, though for the range required there would have to be several changings of the scales. For instance, at one tenth of a minute the scale would have to be changed. At this time value and for a value slightly larger the times could still easily be read. However, as the range increases the deflection on the scale would have to have a very large deflection in order to read the values. For example, an element that is in the range of one to ten minutes used on a scale that is ten inches would require reading the difference of one ten thousandth of an inch from an inked line of a strip of paper. The impracticality of this can readily be seen.

However, on short element times, as far from zero to one one hundreth of a minute on the same scale, it would be practical to read this difference as if it were one tenth of an inch. This difference is readily distinguishable.

There is a method by which the unit could record all the time values. This is to switch the scale for every .01 minutes range. In other words, change the scale at from 0 to .01 minutes to read .01 to .02 etc. This would require a hundred switches for each minute of range and what scale the unit is recording would also have to be recorded. This again appears to be highly impractical;therefore, it appears that this timer would be good only for timing jobs where the approximate time value is known. A scale can be used for this time value as extreme accuracy can be obtained in this manner. It appears that this timer is highly impractical for motion and time study research as it will fail to meet these requirements of the criteria:

(1) The initial cost would be excessive if a long range is obtained.

(2) The time for an operator to read the different scales would be excessive for conversion.

The Thusen Timer

The other alternative is the Thusen timer. It is an interpolated electrical motor recording multiple timer capable of timing one ten thousandth of a minute. The timer times six elements. This timer, as previously stated, has been used for motion and time study research, and has been found satisfactory for research purposes. However, it has an extremely high initial cost.

The Thusen timer operates essentially as described before; however, a complete discussion of its design principles are expressed by Mr. Barnes.[14]

> The automatic timer records time values on a strip of adding machine tape that is advanced intermittently. By merely subtracting successive values, the time of the elemental motion can be obtained. The time recorder records the beginning and ending time values of the motion being studied.
>
> The timer is composed of two main parts; the recorder and the control box. The recorder contains a central shaft with fourteen wheels, each wheel being graduated into 100 increments from 00 to 99. Wheels 1 to 12 revolve at 100 rpm and record time in thousandths and ten thousandths of a minute. Wheel 13b revolves at 1 rpm and records time in tenths and hundredths of a minute. Wheels 1 to 12 record the occurrence of an event (making of a contact, breaking of a contact, breaking of a light beam in a photoelectric cell circuit, or closing of the photoelectric cell circuit) by being struck by a key which is actuated by a time-marker solenoid. The time of contact of the key is so short that no noticeable blurring of the impression results from the continuous rotation of the graduated wheels. This time-marker solenoid is energized momentarily through the control box. The keys and solenoids are located underneath the mechanism.
>
> The wheels receive their motive power from a synchronous motor which revolves at 1800 rpm. This is geared down through gears to revolve wheels 1 to 12 exactly 100 rpm. From this central shaft gears revolve wheel 13a at exactly 1/100 and gears revolve wheel 13b at exactly 1 rpm.
>
> Whenever one of the keys strikes wheels 1 to 12 a double key simultaneously strikes wheels 13a and 13b and the paper advance solenoid operates a mercury switch. The closing of this mercury switch energizes solenoid which operates the paper advance mechanism. This mechanism rotates the rubber rollers which in turn feed the paper and carbon paper through the mechanism. Approximately one-half inch of paper moves forward for each reading, the paper being advanced intermittently at the end of the recording of each event.
>
> The recording of each event consists of the readings from wheels 13a and 13b and one of the wheels 1, 2, 3, etc. Each odd-numbered wheel is associated with the following even-numbered wheel in that the odd records the make of a circuit and the even the break of a circuit. Therefore the recorder is designed to take readings from six such circuits.

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[14] Ralph M. Barnes and E. D. Williams, Jr., "The Automatic Time Recorder," Modern Management, V. LX, May '49, N. 4, P. 4.

This timer comes the closest of any to the criteria for a timer for motion and time study research. However, it does not meet the criteria in that,

(1) Its initial cost is excessive and therefore it is not readily available to industry or institutions.

(2) The timing is not direct, as it has to be subtracted. This is a cumbersome process in this machine because the type wheels are arranged so that the time is added during the timing cycle. This necessitates an analyst to reverse the order of times and subtract.

If the type wheels were arranged to subtract time, the reading would be in order of use. An example of this is shown below.

Thusen

24.3219	Element 1
24.4219	Element 2
24.5219	Element 1 end

To perform the subtraction the numbers have to be reversed so 24.5219 - 24.3219 or .20 minutes.

In the proposed method the time is recorded in this order:

24.3219	Element 1
24.2219	Element 2
24.1219	Element 1 end

The numbers are in the correct order, facilitating an easier subtraction, without the mental or paper reversal - 24.3219-24.1219 or .20 minutes.

Of these two timers, it appears the Thusen timer is the better for motion and time study research. However, as pointed out, the initial cost is too high and the times need to be interpolated.

As the timer is satisfactory in the other respects it appears that this will be the most fruitful type of timer to develop. However, it must be redesigned so that its initial cost can be reduced. The author believes that through several design changes the timer's cost can be substantially reduced and the need for the control box can be eliminated. The control box serves the function of cutting the voltage low enough so that an operator can safely come into contact with the voltage and to activate the striker solenoids. This box consists of relays. The relays close a high voltage circuit and operate the striker solenoids. The problem of operating the proper solenoid becomes complex as two or more have to be operated at the same time.

A discussion of the proposed timer will follow. After the new timer is discussed, a comparison of the Thusen timer and the proposed one will show the design modifications which will reduce the timer's cost without an accompanying loss in efficiency, accuracy or advantages. It is hoped that several desirable features can be accomplished by the redesign, such as the easier identification and subtraction of elemental times.

The Proposed Timer

The proposed timer shall operate on a 110-volt 60-cycle alternating current source. The heart of the timer is a 1/75-hp 1800 rpm synchronous motor. The motor speed was chosen for two reasons. One, the motor is not obtainable in the speed desired. Two, this motor was readily available. The motor is geared down to 1000 rpm by the use of 3/16" 32 p gears. There are five gears in this series, two accomplishing the reduction in speed and the rest acting as an idler and spacer. This spacer gear allows the type wheels to be placed in a position where the striker can hit them to get an impression. The type mechanism is composed of six type wheels each reading from zero to nine. This allows a range of zero to one hundred minutes in increments of one ten thousandths of a minute. The first type wheel turns at 1000 rpm and each successive wheel turns at a ratio of one to ten making the second turn at 100 rpm, the third at 10 rpm, etc. The gearing is arranged so that the numbers are subtracted allowing easier reading. These type wheels were selected because they are a standard assembly.

The element selector is a standard type bar from an adding machine. There are ten numerals ranging from zero to nine. A larger type bar could have been chosen; however it was felt that for the experimental model nine elements would be sufficient. The type bars are depressed by the use of small electromagnets acting somewhat similarly to a relay with the contact bar striking the numerals, and the spring that is already incorporated in the type bar to return the number when the circuit is released. The electromagnets operate on six volts direct current and are energized by the subject. This circuit is in series with a relay that operates the striker solenoid. The action of this unit is as follows: When the subject closes the circuit the appropriate element number is depressed and the striker comes up striking the element number and the type wheels, giving the start or end of the element and the time at which it occurred.

This completes the timing mechanism.

The paper advance mechanism is composed of six parts. They are the paper holder, the paper guide, the paper platten, the paper pressure roll, the paper advance solenoid and the microswitch.

The paper holder is composed of a rod that fits through the center of the roll of paper and is threaded on one end and has a knob on the other. This rod fits through the frame of the machine and screws directly to the other side. This is done to keep the paper inside of the machine instead of on the top as in the Thusen timer.

The paper guide is made of 3/4 inch diameter aluminum stock and serves the purpose of keeping the paper level and straight as it goes through the printing mechanism. It is made out of aluminum for the sake of keeping the weight down. It is fastened directly to the frame of the machine.

The paper platten is a standard typewriter platten cut down in length. Its purpose is to advance the paper through the machine after each printing. It retains its knobs so that the paper can be fed through the machine manually.

The paper pressure roll is a standard rubber roller from a typewriter. Its purpose is to hold the paper against the platten so that it can be fed through the machine. The roll is mounted in two oblong holes so that it can be raised or lowered. This allows the roll to be lifted to start the paper and to adjust it so that the paper will feed straight. The roll is adjusted by two thumb screws on the top of the machine.

The paper advance solenoid actuates the platten when the circuit is energized. It is a 110-volts 60-cycle alternating current solenoid. The solenoid engages a pawl in the ratchet of the platten and pulls the paper forward approximately one-half inch for each actuation. This is adjustable by the positioning of the solenoid. The pawl is returned to its normal position by a spring. The solenoid is energized by the microswitch. The microswitch is operated by the return stroke of the striker solenoid, thereby allowing the paper to be advanced after the printing of the time value.

Striker Mechanism

The striker mechansim is composed of a solenoid, a sliding cam, and a striker platten.

The striker solenoid operates on a 110-volt 60-cycle alternating current. When the solenoid is energized, it pulls the sliding cam. The sliding cam pushes the striker platten, a hard rubber bar, against the type wheels which makes an impression of the element and the time. A spring returns the solenoid when the circuit is released. The striker platten returns to its normal position by gravity and is ready for the next timing. On the return stroke a microswitch is actuated which advances the paper.

The paper is a 5-1/2 roll of single use carbon and a sheet of white paper. The use of this eliminates the need for an inked ribbon.

The frame is made of 1/4" aluminum plate, with holes drilled so that all parts can be directly mounted to it.

The foregoing parts are shown with their specifications on Figures 1 to 38. (See Appendix)

As can be seen, all standard parts are used wherever possible, and those that have to be made are of a simple design and are designed with the stress on ease of construction. With these two principles in mind the first objective for the redesign is accomplished, that is, the reduction in cost of the timer. Also the number of elements that can be timed has increased from six to nine. The numbers are easier to read, since they need not be reversed before subtraction. The paper is incorporated with the carbon, eliminating the need for two rolls and the difficulty of aligning them. The type wheels have been cut down from fourteen to six and have been changed from special wheels to standard ones. The type wheels only require one pinion wheel for indexing whereas the Thusen required twelve. The number of gears has been reduced from over ten to three. The control box has been eliminated. These factors are believed to be substantial improvements over the design originally made by Thusen.

Operation of the Time Recorder

As was discussed and can be seen from the previous section, the time recorder is essentially a device which is dependent on a 110-volts, 60-cycles alternating current source. This power serves the entire machine. The current enters the machine and directly drives a synchronous motor. The motor in turn drives a series of gears which drives a counting mechanism. The counting mechanism is made up of type wheels of which the last wheel turns at 1000 revolutions per minute, making the reading on this wheel register one ten thousandth of a minute, as the wheels have ten numbers ranging from 0 to 9 on the circumference. This is the heart of the timer and is the critical measurement of time, as any slowing or speeding of the motor will disturb the true time value. A slight change by the speeding or slowing of the type wheels due to the striker should be compensated by the synchronous motor.

The other use of the power will be to drive the auxiliary mechanism. These are:

(1) The low voltage source for the actuation of the circuit and operation of the relay.

(2) The power for the striker solenoid.

(3) The power for the paper advance solenoid.

The low voltage source for the actuation of the circuit number and the operation of the relay is obtained from a 12-volts alternating current transformer. This voltage runs from the machine to the switch, which is at the point of the study, and returns to the machine activating the particular circuit number and the relay. The circuit numbers' function is to enable the analyst to identify the particular motion later when the readings are analyzed. The function of the relay is twofold, one being that a high voltage source is applied to the striker solenoid, two, the relay is of a type which will only deliver a single short impulse to the striker mechanism so that no matter how long the circuit is energized the striker will not rest against the type wheels, thereby causing a smear on the paper.

The power for the striker solenoid is obtained through the relay, as was mentioned above. The coil windings are energized by a six-volts source and the contacts on the relay acting as the switch for the high voltage source. The high voltage source is 110 volts alternating current, 60 cycles operating the striker solenoid. The result of this is to drive a platten against the type wheels making the impression or permanent record.

The power for the paper advance solenoid is again a 110-volt, 60-cycle alternating current source. This voltage is obtained from a micro-switch. The micro-switch is placed under the plunger of the striker mechanism and as the plunger returns from its striking of the type wheels it hits the micro-switch and this gives an impulse of electricity which activates the paper advance solenoid. This allows the paper to be advanced just after the printing, and it is now ready for the next recording. The paper is ejected outside of the machine or, if desired, a box could be attached to the outside of the machine which would catch the paper and could even separate the carbon by a separation plate from the paper.

The foregoing discussion gives a fairly comprehensive view of what takes place inside the machine as a study is made, but there are several things that must be performed by the analyst making the study.

Procedures Preliminary To Use

The first thing, of course, is to program the machine's use so that it can be effectively used for the particular study being made. This is done very similarly to the procedure used in taking time studies. Of course, these must be viewed in terms of how the machine operates. These are:

(1) A write-up of the job or element being timed. This is necessary so that later when the data is timed and analyzed the analyst will have a complete check on the study with full comprehension of what has taken place.

(2) A deciding of what is the start and end point so that the elements will be clearly defined.

(3) A breakdown of elements so that the proper variables will be measured.

(4) A decision as to what type of switch will be used to energize the circuit. Some of these are:

A. Micro-switch which is activated by the subject. On this type, definite contact has to be made so as to activate the switch. It must be remembered that the operation of the switch could require extra time if it is not properly located or used with motions, and that this definite contact could introduce serious error.

B. Electromagnet switch which is operated by the operator wearing a small magnet connected to the subject's body member. As the magnet is brought in the immediate vicinity of the switch, it is closed. The analyst must remember that this has the fault of not being an exact location; however, it could be controlled if carefully placed within a fourth of an inch.

C. Photoelectric cell. This is based upon the interruption of a light beam by the subject which transfers a small current to a relay which in turn operates the mechanism. This must have a comprartively constant light in the surrounding so that the device will not be disrupted by shadows, changes in sunlight, etc.

D. By the actual depressing of a switch by the analyst. This of course has the disadvantage of the analyst's reaction time and in all probability would not be used by the operator.

There are other methods that could be devised but it is not the purpose to go into all of the switch mechanisms but rather to give an insight as to what considerations are necessary if an arrangement of this type is used.

(5) A decision of how the circuits are to be used in addition to the definite using of the circuit numbers. This is probably best explained by example. Such an example would be:

Case I. A job consists of four elements. The job has an element sequence of one, two, three, four and one, etc. This repeats itself throughout the study. There is no lag or time delay between successive elements. The machine could be set up in this case using only four circuits, each recording the starting time of the element. The starting point of element two would be the ending point of element one.

Case II. Consider now the case where there is essentially the same job except that there is a delay between one of the elements. This would mean that one element ends, then there is a lag before the next starts. This would require some means to identify the end point of the element preceding the lag. This is accomplished by using an extra element numeral in order to identify the end of the element. An alternative method would be to identify all of the elements end points by the use of numeral number 0. At the end point a double-pole single-throw micro-switch is connected with it.

Case III. This is a case where the elements do not occur in sequence. That is, one time they may occur in sequence and the second cycle they would appear one, three, two, four. This could be performed the same as in Case II.

Case IV. This is where one or more elements could start in the middle of another element and end at any time in the same element or outside in any of the other elements.

Start ________________________ End

Start ________________________________ End

Start _______________ End

Start __________________ End

This can again be handled by Case II. It is the writer's belief that this covers almost all types of jobs that could appear. However, if this does not, it is felt that the solution could easily be obtained by some additional reasoning on the part of the analyst.

(6) The setting of the circuits which include the actual physical layout of the switches.

(7) The placing of paper into the machine. This is done by removing the cover, taking out the paper rod by unscrewing the knurled knobs on the side of the machine and pulling it out, putting in a roll of paper so that it feeds from the bottom and replacing the paper screw. The paper is fed through the counter to the paper advance. It is started in the paper advance, and the plastic knob is turned counterclockwise. The paper is then fed outside of the macine.

The machine is now ready for a test which should be performed before and after the machine is to be used for a study. The first test is to simply run through the order or sequence of elements and check the elements and printing to see if, one, the machine is making all of the circuits or elements in the proper order (that is, circuit one measures element one, circuit two measures element two, etc.), two, to see if all circuits are wired or closed, three, to see that there is not a mechanical failure.

A second test could be performed that would allow a complete check of the machine, that is, to have a timer of known accuracy energize the circuit and check the printed value against the known. This, however, is a cumbersome test and in all probability would not be necessary except on a periodical check--say monthly or weekly, etc., depending upon use.

Care and Operation of the Machine During the Study

The machine is completely automatic during the study except where the analyst actuates the switch at the start and stop of the element. In light of this there are two things that are necessary to check during the operation. One is to see that the supply of paper is sufficient and that it is feeding properly. Two, that the machine is printing the required number of readings.

There is one additional point the analyst might like to check if circuits permit and that is to connect an additional circuit to show or make a record of foreign elements by depressing a key. This means that the time for the particular element is rejected. An additional jack is provided for this purpose and is already wired; it is circuit nine.

After the study is made the same test as prescribed before is to be performed and then the machine is turned off. The paper is advanced with the plastic knob until the printed numbers cease to appear, and then the paper is torn off.

In the storage of the machine it is advisable to release the paper advance roll to prevent flat spots on the rollers, and to cover the machine so that no dust settles upon it.

CHAPTER IV

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Chapter III has shown the overall design of the motion and time study timer and its operating principle. The purpose of this chapter is to review the design for possible weaknesses and to describe which of the components of the machine may have to be redesigned. It is also the purpose of this chapter to evaluate the device in terms of what is the maximum and minimum operational characteristics so that one may carry on the development of the device if the needs for a particular service justify further investigation.

Discussion of Components

Paper advance mechanism.--The paper advance mechanism will operate properly without any modification in design. It consists of the paper holder, two flat springs (to align and keep tension on the paper roll), a paper guide (to feed the paper at the correct height so as to keep the paper from resting against the type wheels or the platten), a paper pressure roll (to force the paper against the paper platten; it is made adjustable so that the paper feed can be kept straight in the machine), a paper advance platten (to pull the paper through the machine), a pawl (to engage the ratchet on the paper advance platten), a solenoid (to advance the pawl), a spring to return the solenoid to operating position, a spring to engage the pawl in the ratchet and a spring to engage the ratchet (to keep the platten from allowing the paper to slip back, since the slipping back of the paper could cause the machine to double print, an undesirable result). The entire paper advance mechanism was built, and it appears satisfactory as shown in the drawings. There are no parts which seem to cause trouble.

The striker mechanism.--The striker mechanism was built and operated; however, it was not assembled in the machine and therefore may develop additional faults which are discussed later in detail.

It consists of a platten (to receive the impression from the type face and transfer it to the paper), a rod (to transmit the force of the solenoid to the platten), a cam (to change the direction of force from the solenoid--which is in a horizontal plane--to a vertical plane), and a solenoid (to produce the force for the striker mechanism). This complete unit with the exception of the platten has been built at the time of writing and it works satisfactorily. There are two parts which may cause trouble in operation. One is the platten which may not be designed wide enough to clearly distinguish the last number; however, it is felt that one-half of two numbers will produce a readable value. The other is the size of the solenoid, for if the solenoid is of insufficient power clear readings will not be obtained. These two faults can be overcome if they give difficulty in operation and therefore, the design principle is felt to be satisfactory at the time of writing.

The element type mechanism.--The element type mechanism has been built. However, some design modifications (as described below) are highly desirable.

This mechanism serves the purpose of identifying the elements and is composed of a type bar (which identifies the particular element), a mounting block (which holds the element type bar and cams), cams (to transfer a horizontal motion to a vertical motion), pull rods (which transmit the force of relay solenoids to the cams), and the relay solenoids (which initiate the force for the element type bar). This unit has been completely built and it was found to operate. There are two modifications which should be incorporated in it. One is the change of design in the pull rod. The pull rods should be threaded on the end that connects with the relay solenoid. Two nuts should be placed on the threaded end (one before and one after the solenoid arm). This would facilitate easier assembly and adjustment of the device. The other modification would be to change the design of the mounting block so that the element type bar will rest one-fourth inch closer to the center of the machine. (This part works as it is designed; however, with these changes the operation would be smoother, and the wear on the part in operation would be reduced.) This change would not affect any other part in the machine. Of the parts built, the mounting block, after its change, was found to be satisfactory in that it functioned properly.

The circuit.--It supplies power to the different components of the machine. This circuit was not built and, therefore, no definite statements as to its operational characteristics can be made. In view of this, several people were consulted in order to see if any parts or the overall principles were incorrect and the concensus of opinion was that the circuit should not give any major difficulty in operation that could not be corrected with a minimum of effort. Such a change might be a slightly higher increase in voltage for the operation of the relays. The general circuit, however, should give no difficulty in operation.

<u>The counter mechanism</u>.--The counter mechanism has the greatest possibility for weaknesses in operation. It consists of a motor (to give a source of power), a series of gears (to transmit the power to the type wheels and to accomplish the reduction in speed), the type wheels (to furnish the time values for the machine) and the pinion (to index the succeeding type wheels proportional to the time reading desired). This unit was not assembled. It could have two possible difficulties. One is that the speed of operation--which is slightly higher than that recommended--would cause excessive wear on the part. This could be overcome by the inclusion of a bushing in the type wheel that would stand up under the increased wear. The other difficulty is that the springs incorporated as an integral part of the type wheels are not of sufficient strength--thereby allowing the type wheels to index more than one numeral at a time. This is a fault that could not be corrected without considerable difficulty, as it would require experimentation on spring strengths until the proper one is found. If this difficulty does occur, the only solution would be to redesign the machine for another counter unit or to reduce the gearing of the machine so that ti will read only to 0.001 minutes. This, however, would reduce the effectiveness of the machine to the point where it no longer meets the criteria for a timer for motion and time study research. The machine would still have limited use in timing fairly long elements such as those in the neighborhood of 0.002 minutes in duration and it would still be effective for multiple element timing.

Conclusions

In view of the foregoing discussion, it appears that the machine is definitely a practical design, although two of the criteria are not met. These are:

(1) The machine does not read in direct times.

(2) The machine--due to the counter mechanism--may not read to one ten thousandth of a minute. At this time, this condition appears to be met, but it is listed as an objection, for no test was made and therefore no conclusion could be definitely drawn concerning its satisfactory operation.

The machine should cost in the neighborhood of four hundred dollars--one hundred for parts and three hundred for labor.* This is an amount that could be afforded by individuals or institutions.

The cost of operation would be rather low as only single use carbon and paper is used.

The device would have a permanent record. This is accomplished through the entire design of the machine and no difficulty in obtaining a permanent record is contemplated. As was discussed a little earlier, the platten size may have to be increased in order to obtain a recognizable last digit.

The machine would be capable of timing 10 successive elements (See Case I, Chapter III, page 41) or 9 non-successive elements (See Case II, Chapter III, page 42). As there are components of the machine that accomplish the above purpose, it appears that this fulfills the criteria of multiple element timing.

In summary, the machine will fulfill the criteria with the possible exceptions mentioned before. In any event the machine would be capable of 0.001 a minute, and would be practical for limited research

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*This is an estimate based on approximately 120 hours of an experienced machinist's time at $2.50/hour.

purposes, or if it operates as designed, the machine will meet the criteria for a motion and time study research timer with a compromise of not being able to read in direct time values.

Recommendations

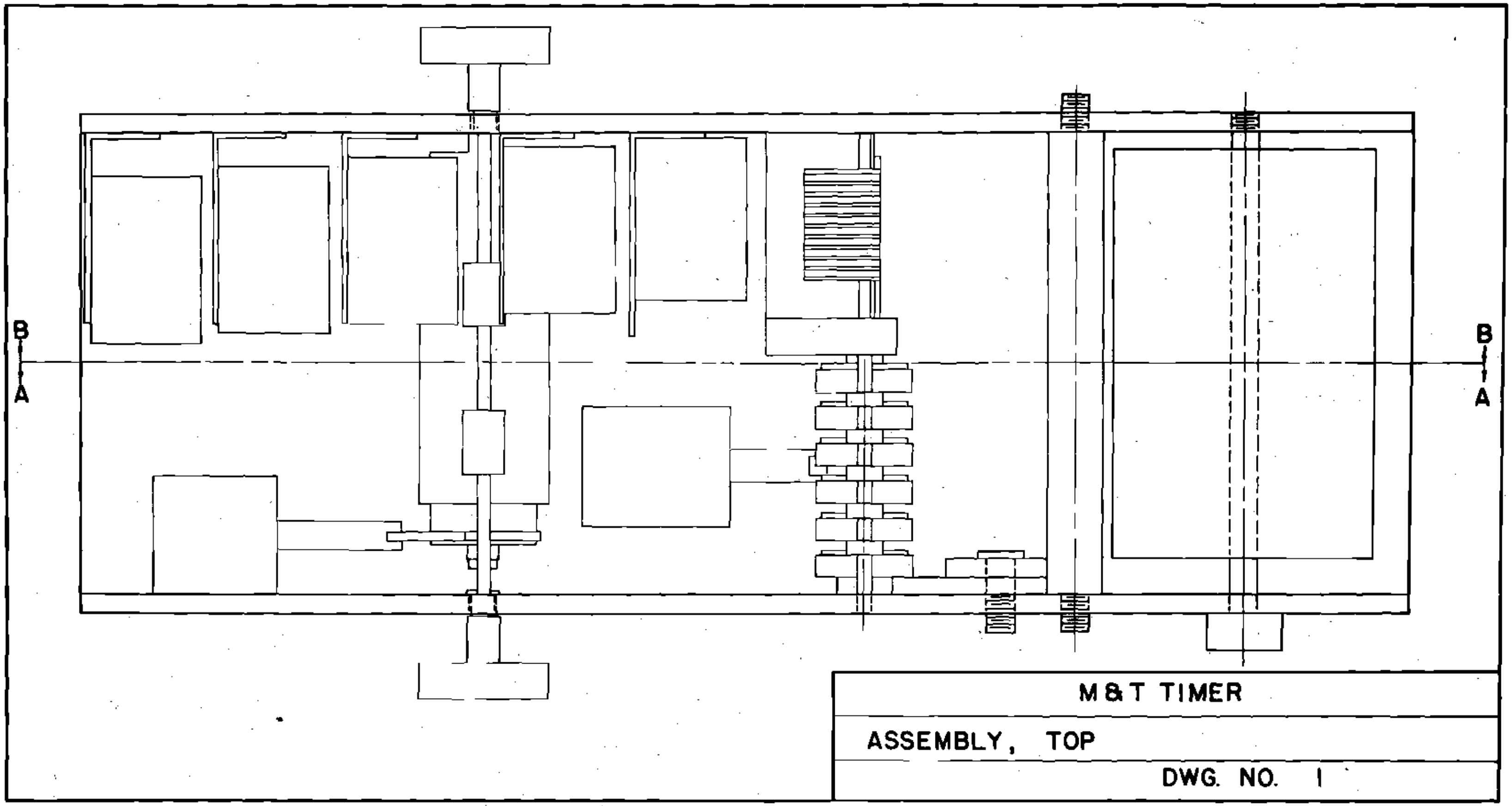
It is recommended that:

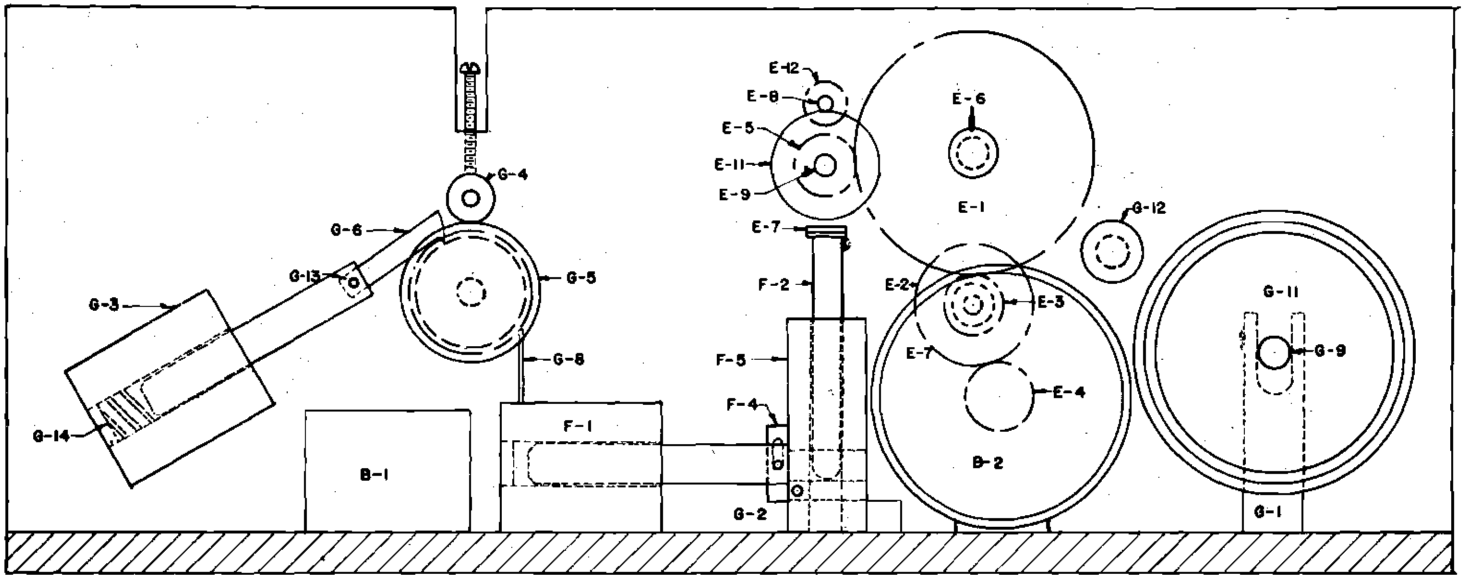
(1) The machine be built and completely assembled. This will allow complete testing and facilitate further redesign and development if necessary.

(2) The machine be tested so that its limitations can be discovered. Such a limitation would be the speed with which successive elements could be timed without a loss in accuracy.

(3) That the machine be built by an experienced machinist with proper facilities and machines. This will eliminate some of the inaccuracies in the initial building of the components and allow the machine to function properly for a greater period of time.

APPENDIX

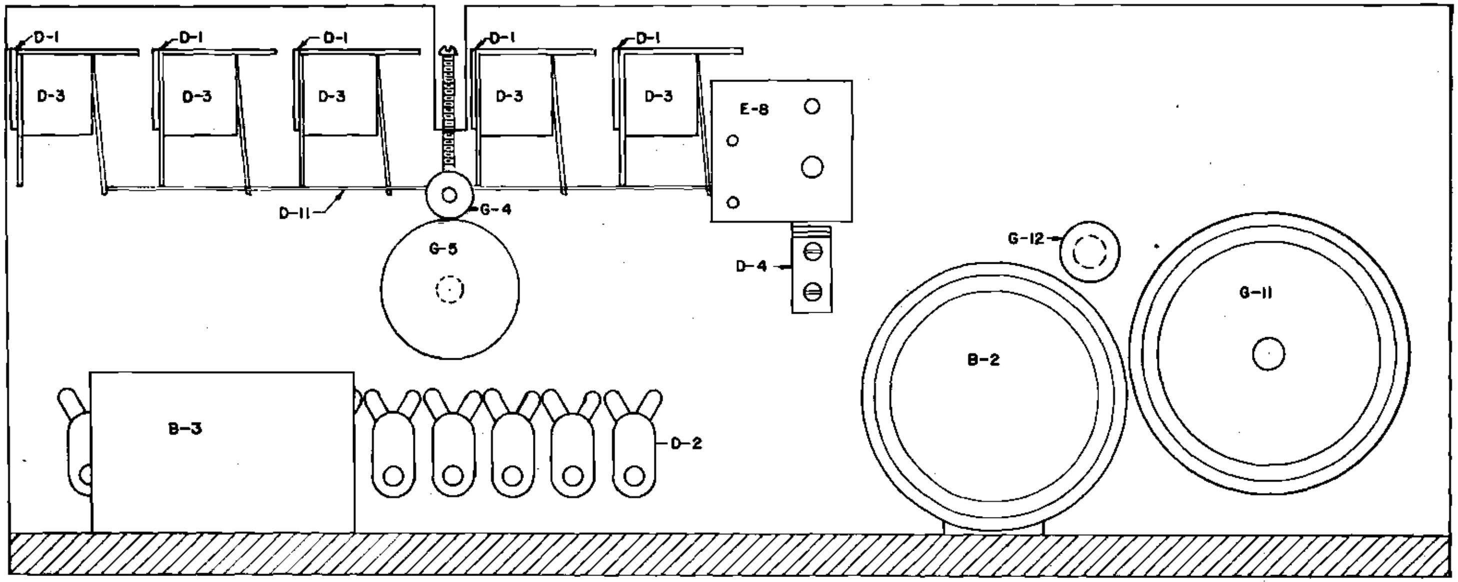

B
A
B
A
M & T TIMER
ASSEMBLY, TOP
DWG. NO. 1



M & T TIMER

ASSEMBLY SECTION AA

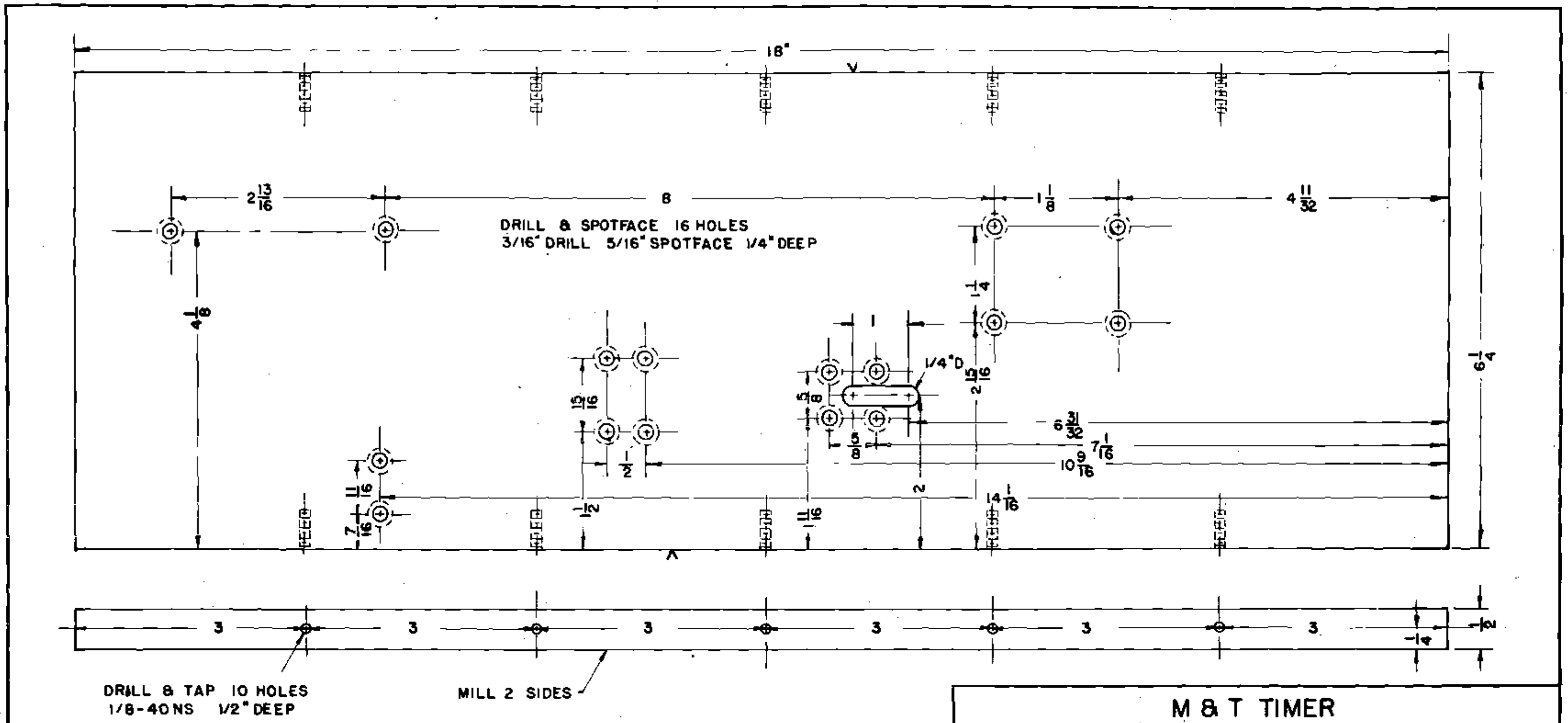
DWG. NO. 2



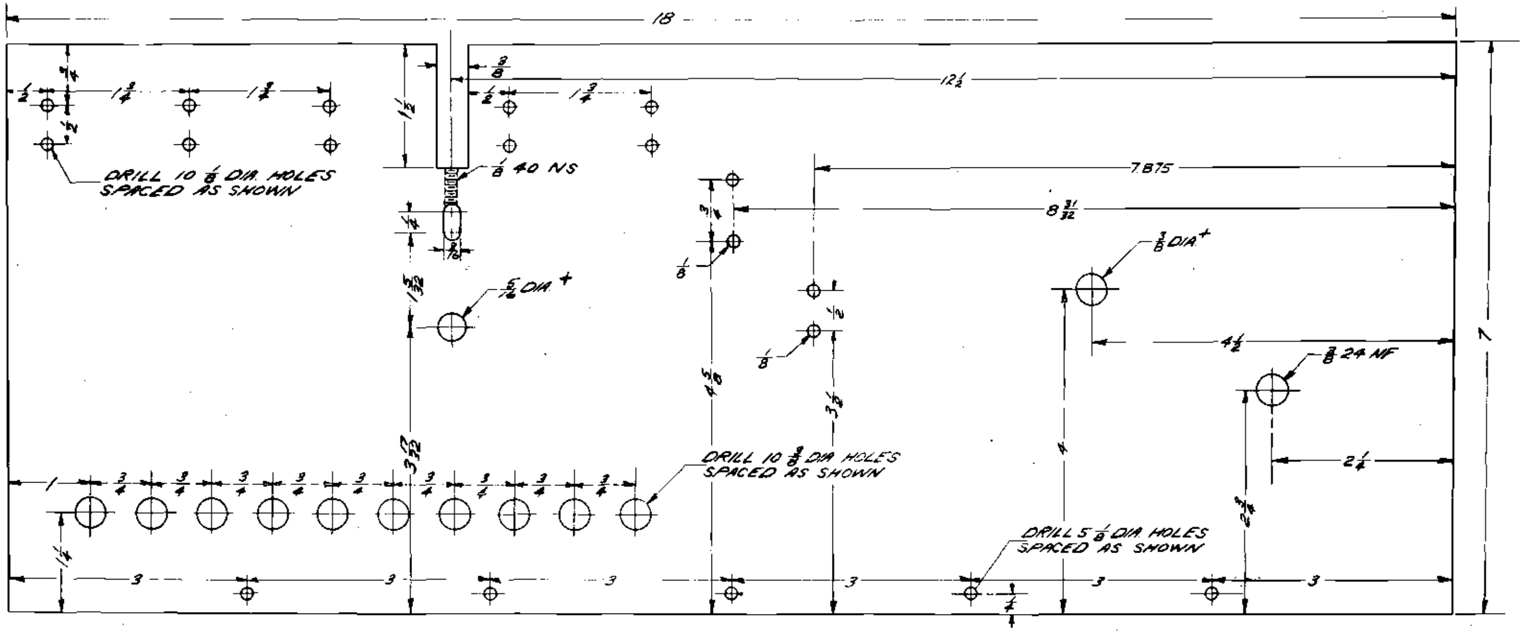
M & T TIMER

ASSEMBLY SECTION BB

DWG. NO. 3

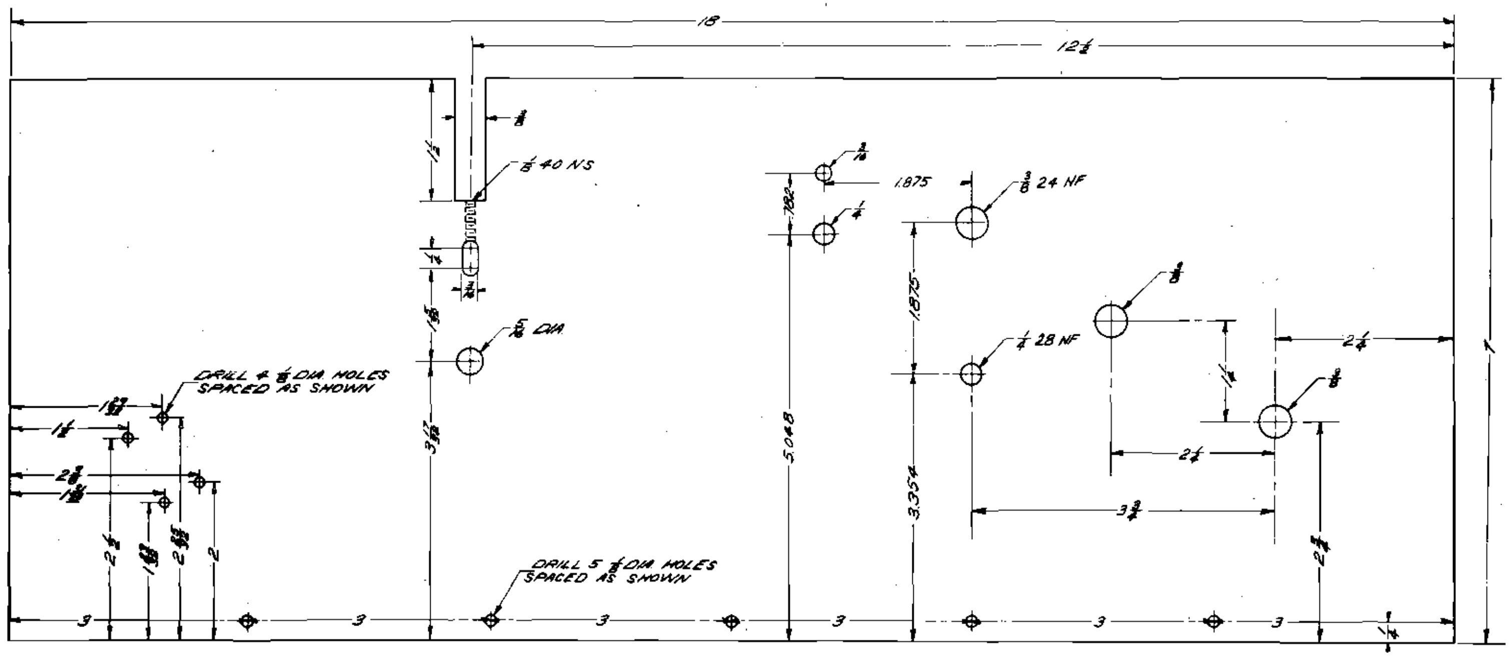


M & T TIMER	
FRAME	
PART NO. A-1,	DWG. NO. 4



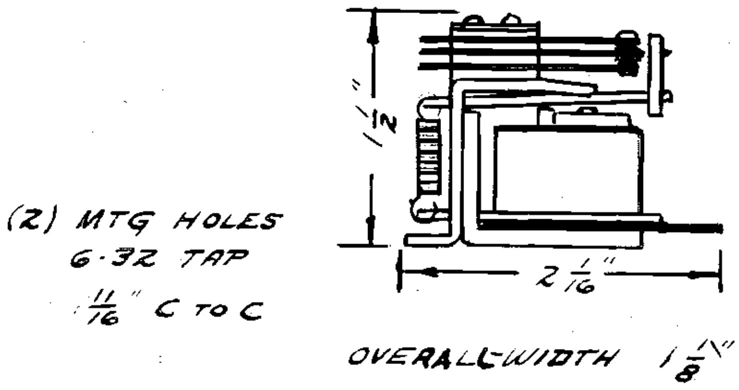
1/4" PLATE

M & T TIMER	
FRAME	
PART NO. A-2,	DWG. NO. 5



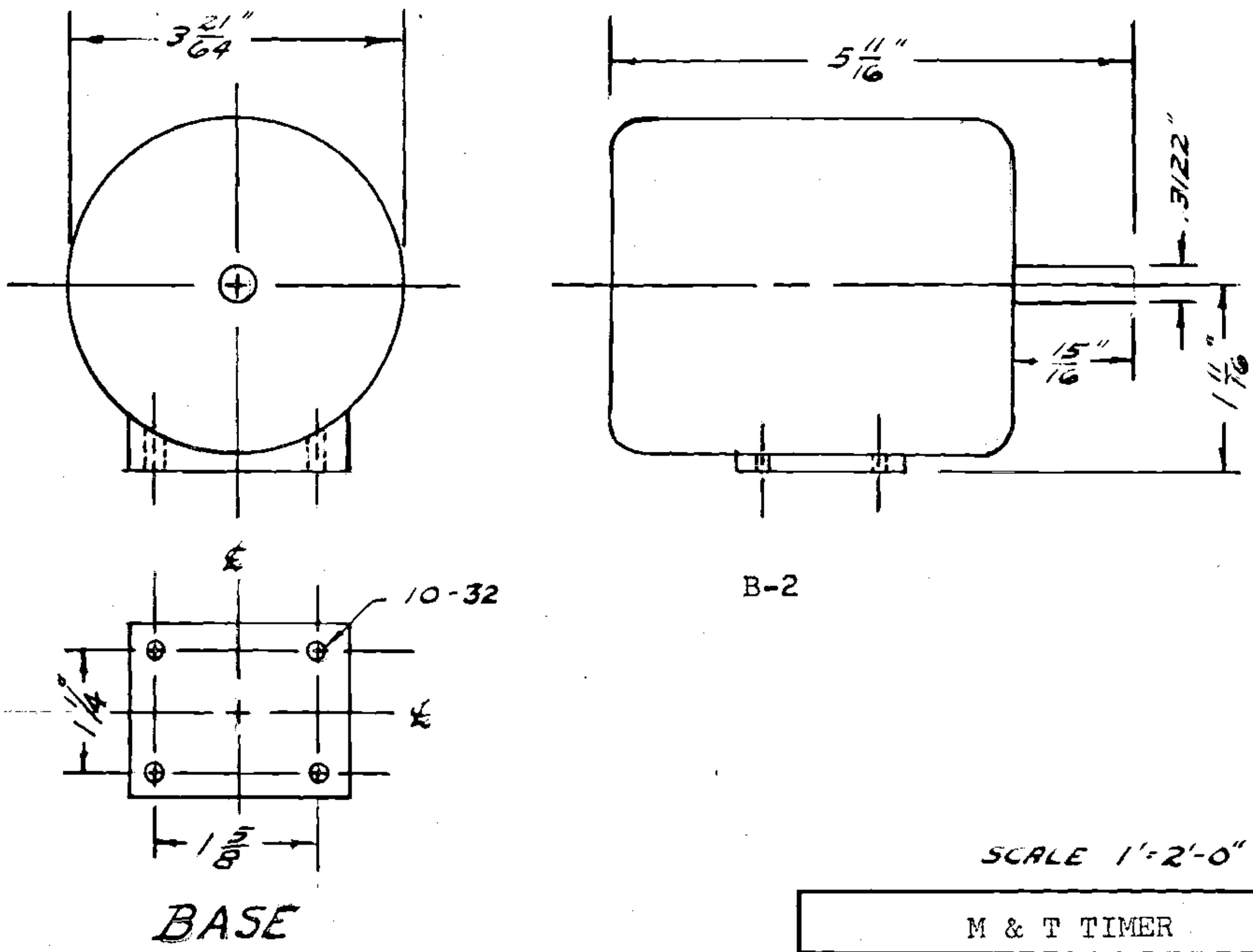
1/4" PLATE

M & T TIMER
FRAME
PART NO. A-3, DWG. NO. 6



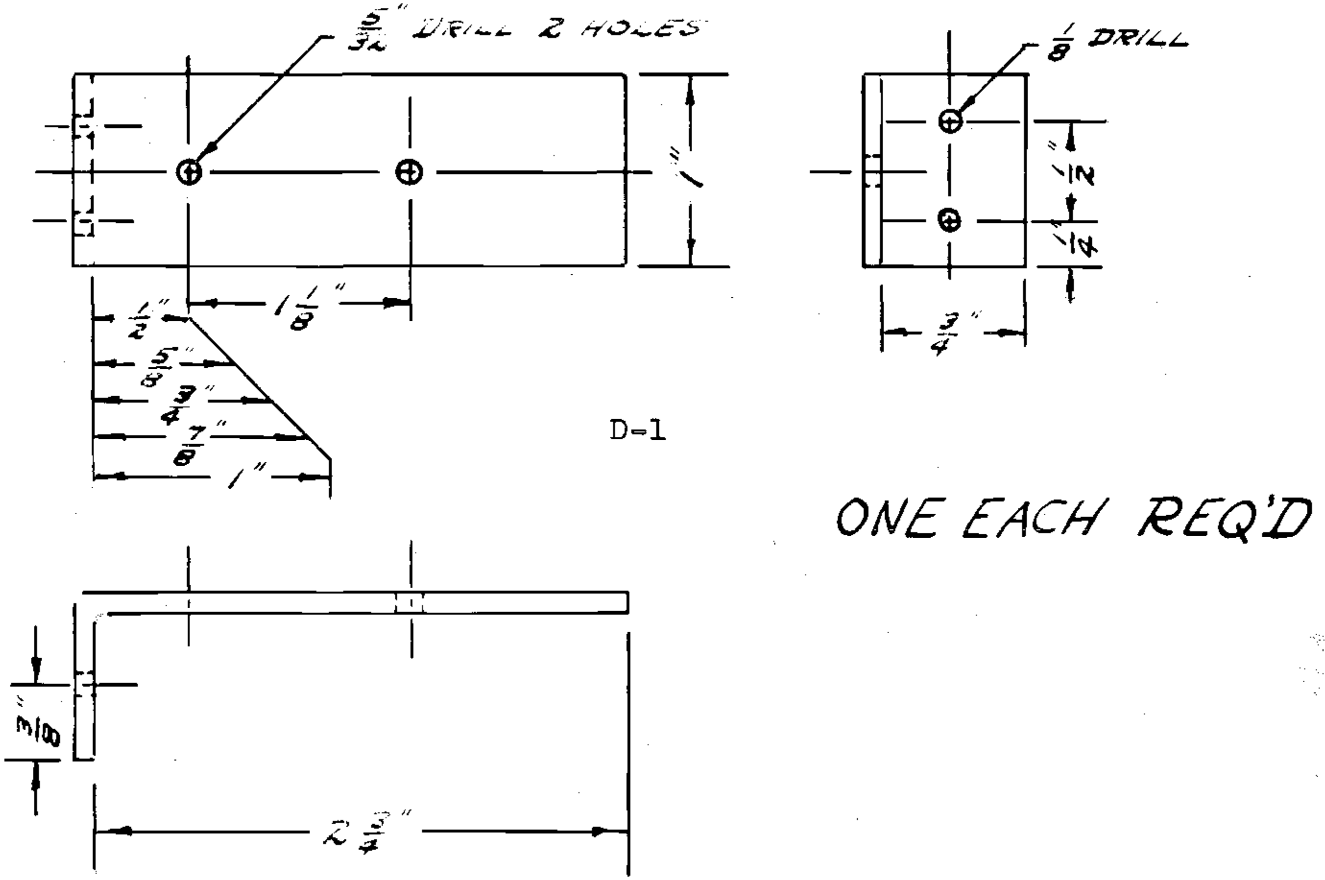
B-1

M & T TIMER	
ELECTRICAL	
Part B-1	Dwg No. 22



SCALE 1"=2'-0"

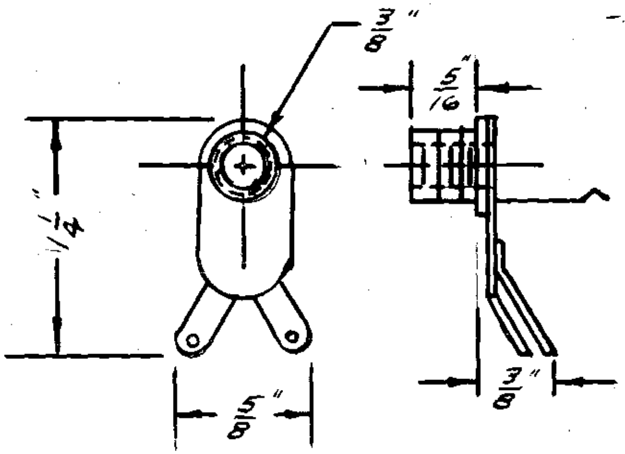
M & T TIMER
ELECTRICAL
Part B-2   Dwg No. 23



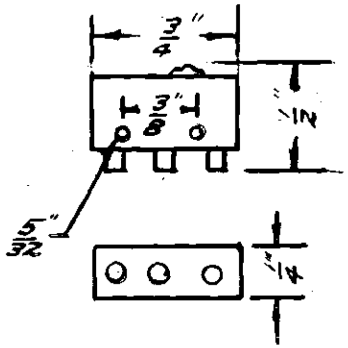
M & T TIMER

ELEMENT MECHANISM

Part D-1 Dwg No. 14

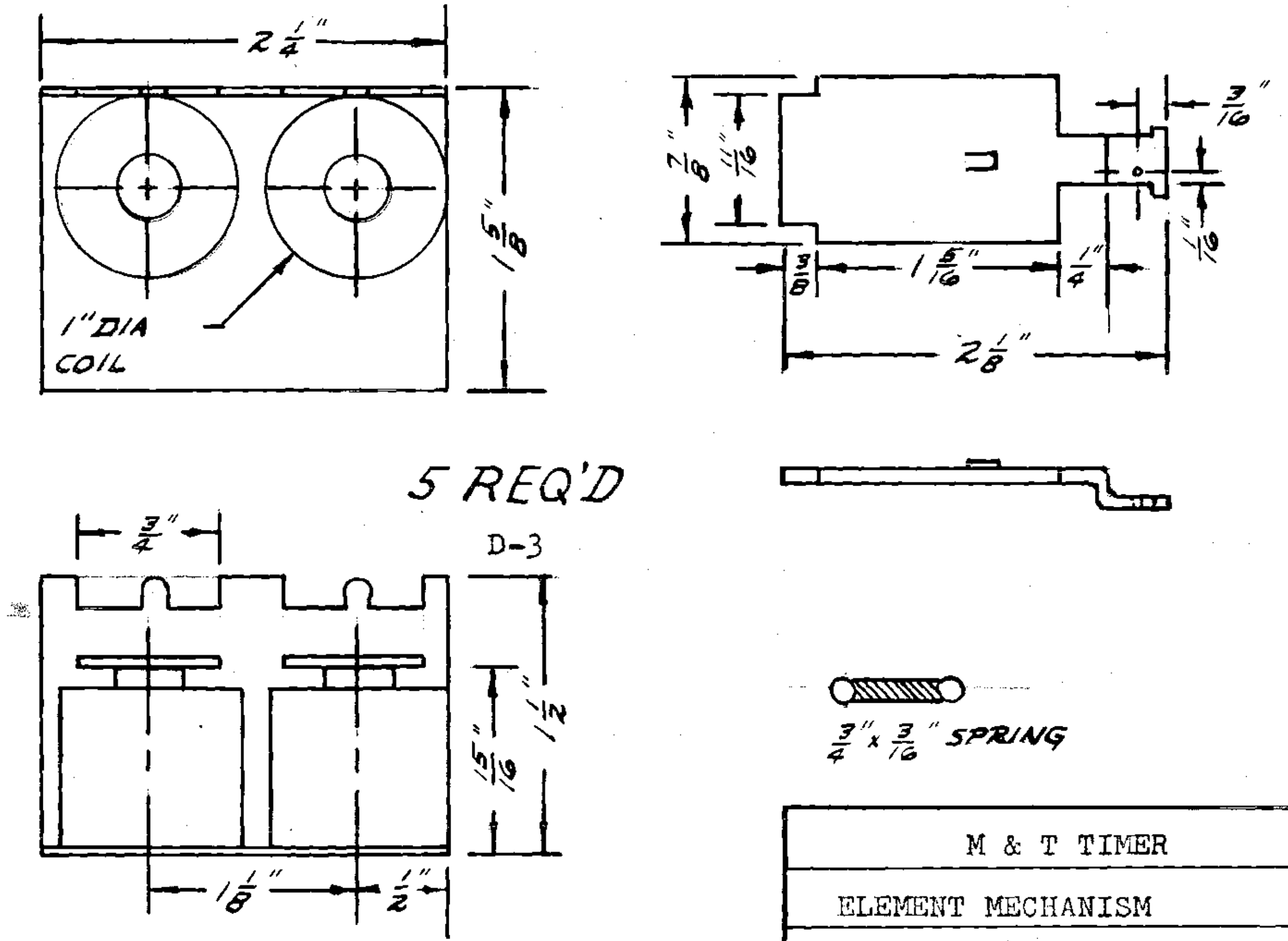


D-2



G-2

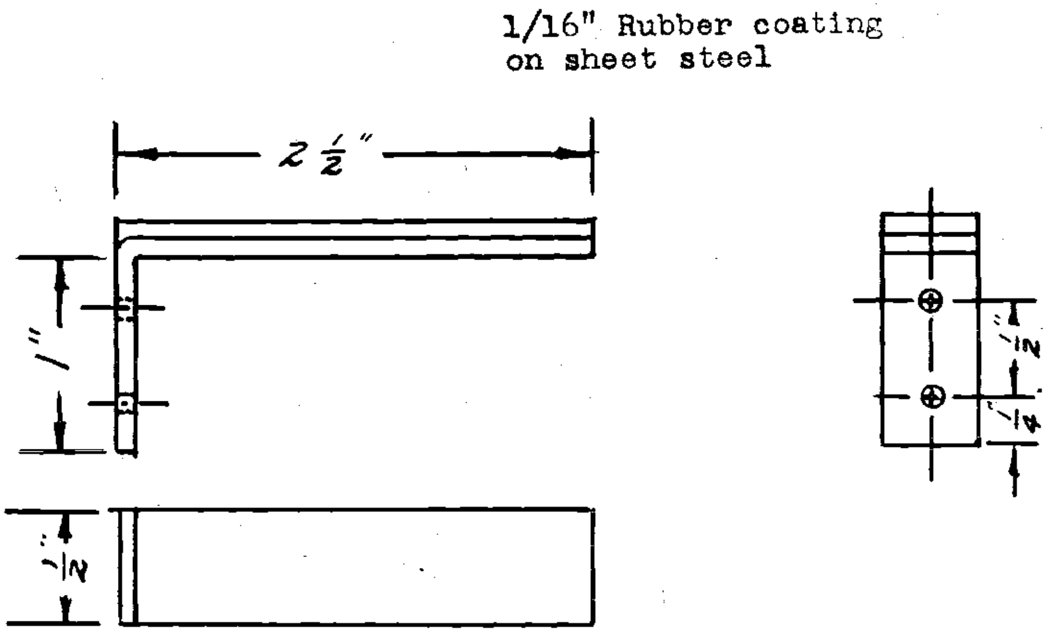
M & T TIMER	
Part D2, G2	Dwg No 16



M & T TIMER

ELEMENT MECHANISM

Part D-3 Dwg No. 20



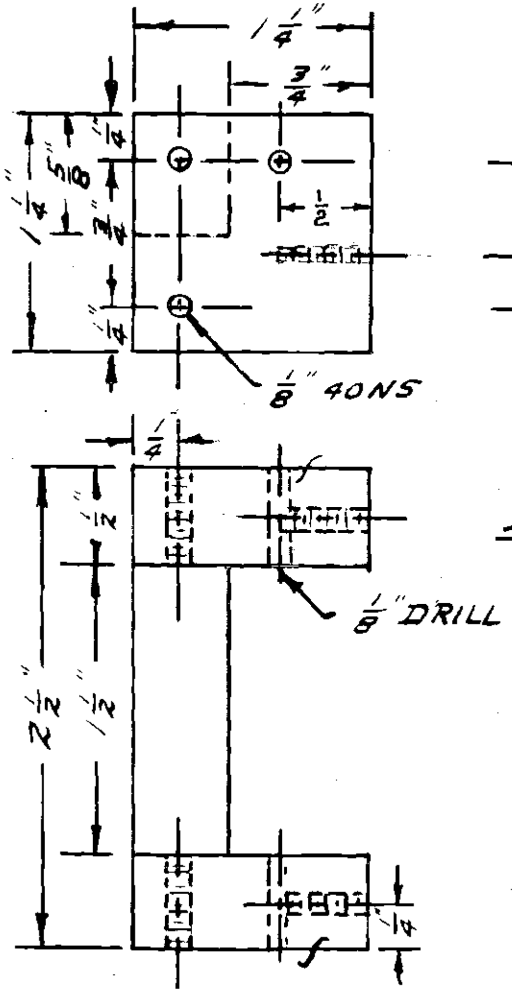
D-4

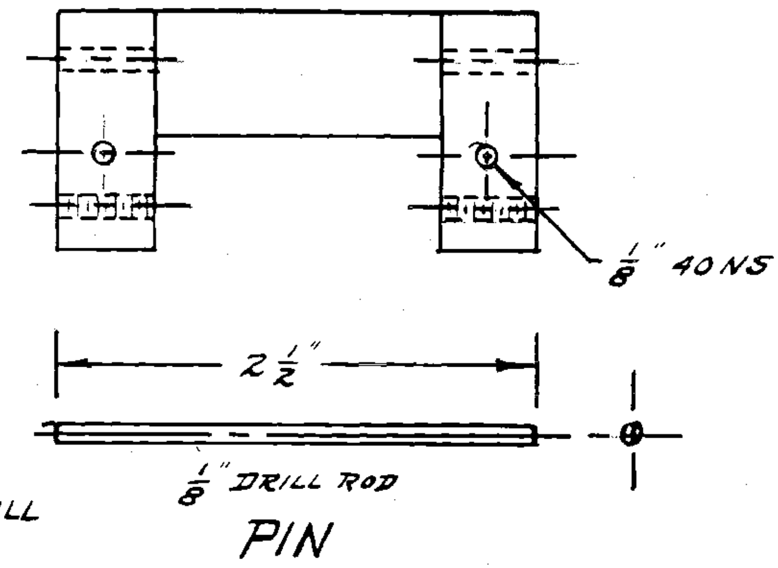
M & T TIMER

ELEMENT MECHANISM

Part D-4 Dwg No. 18

D-5



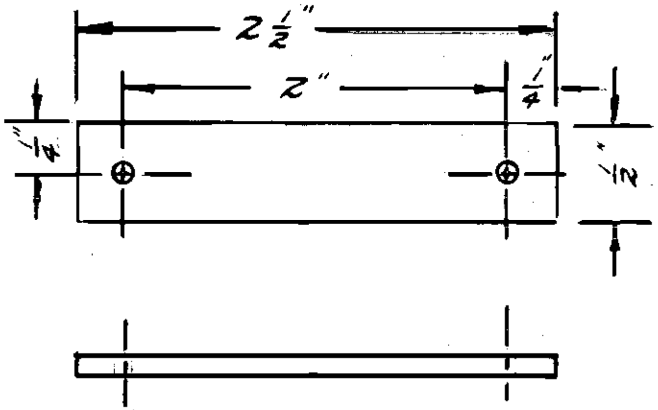


D-7

M & T TIMER

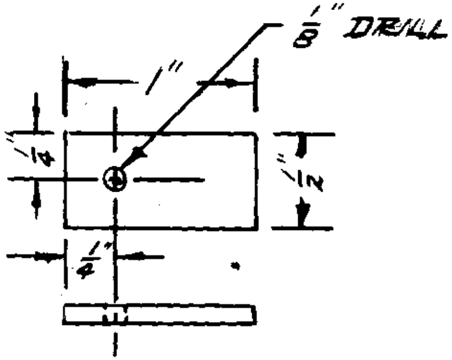
ELEMENT MECHANISM

Part D5, D7, Dwg No 19

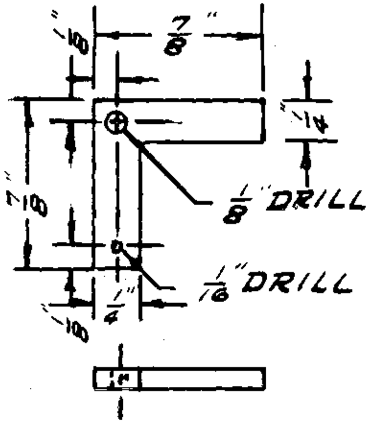


D-6

M & T TIMER	
ELEMENT MECHANISM	
Part D-6	Dwg No. 15

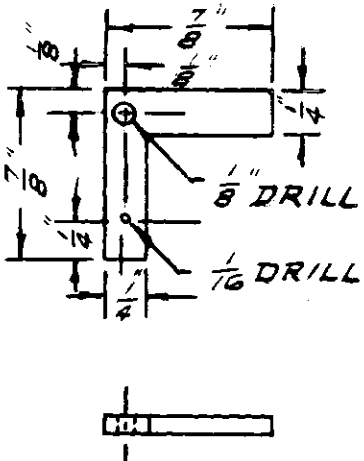


D-8 18 GAGE BRASS STOCK



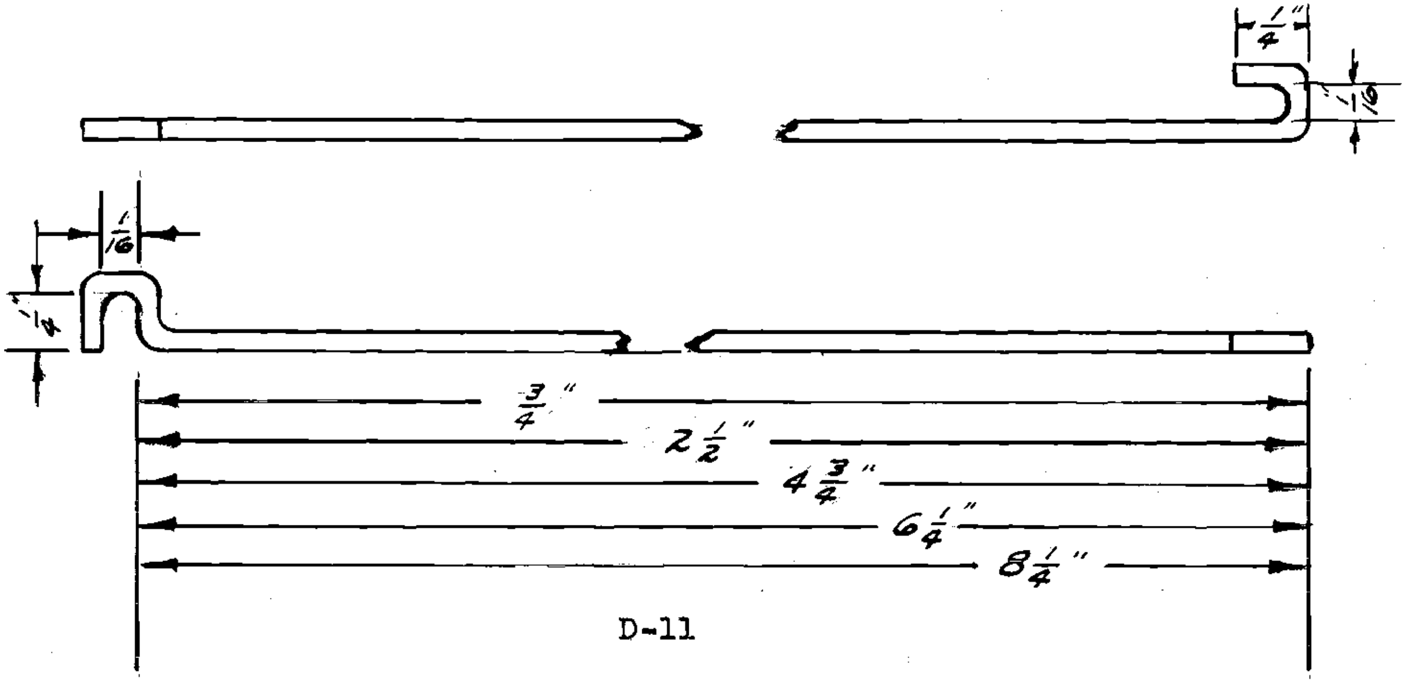
11 GAGE

D-9



D-10

M & T TIMER
ELEMENT MECHANISM
Part D8,D9,D10 Dwg no 17

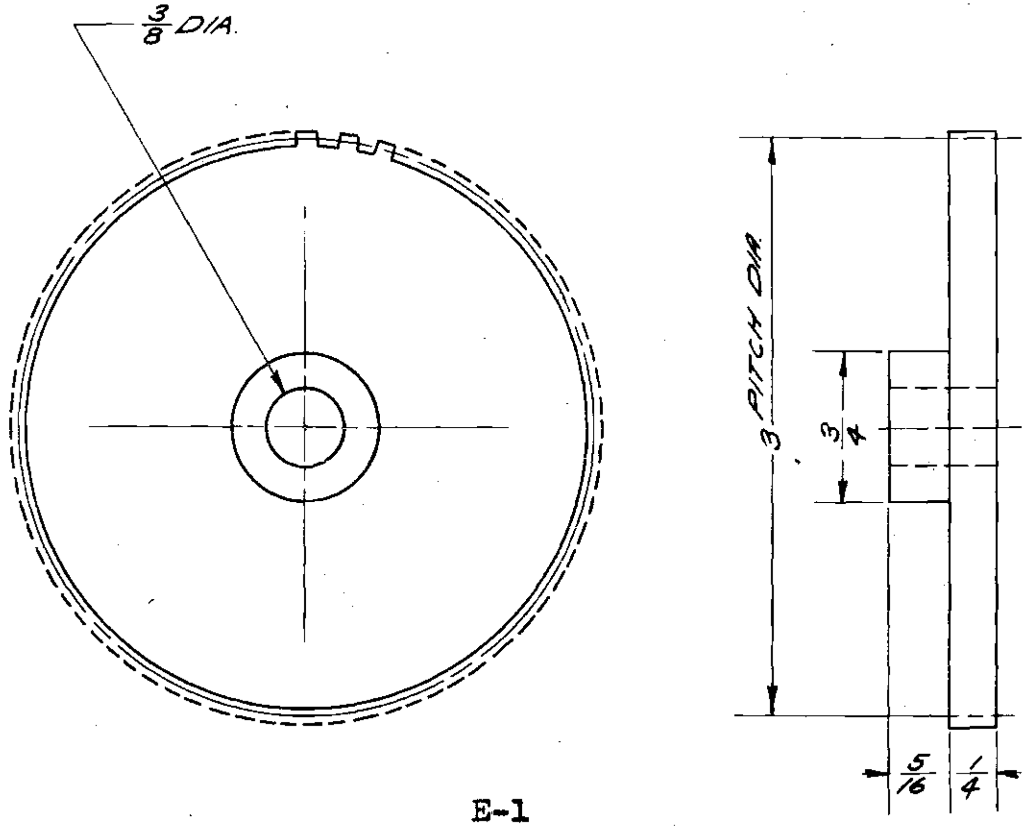


D-11

TWO REQ'D EACH DIMENSION

NOT TO SCALE

M & T TIMER
ELEMENT MECHANISM
Part D-11 Dwg No. 21

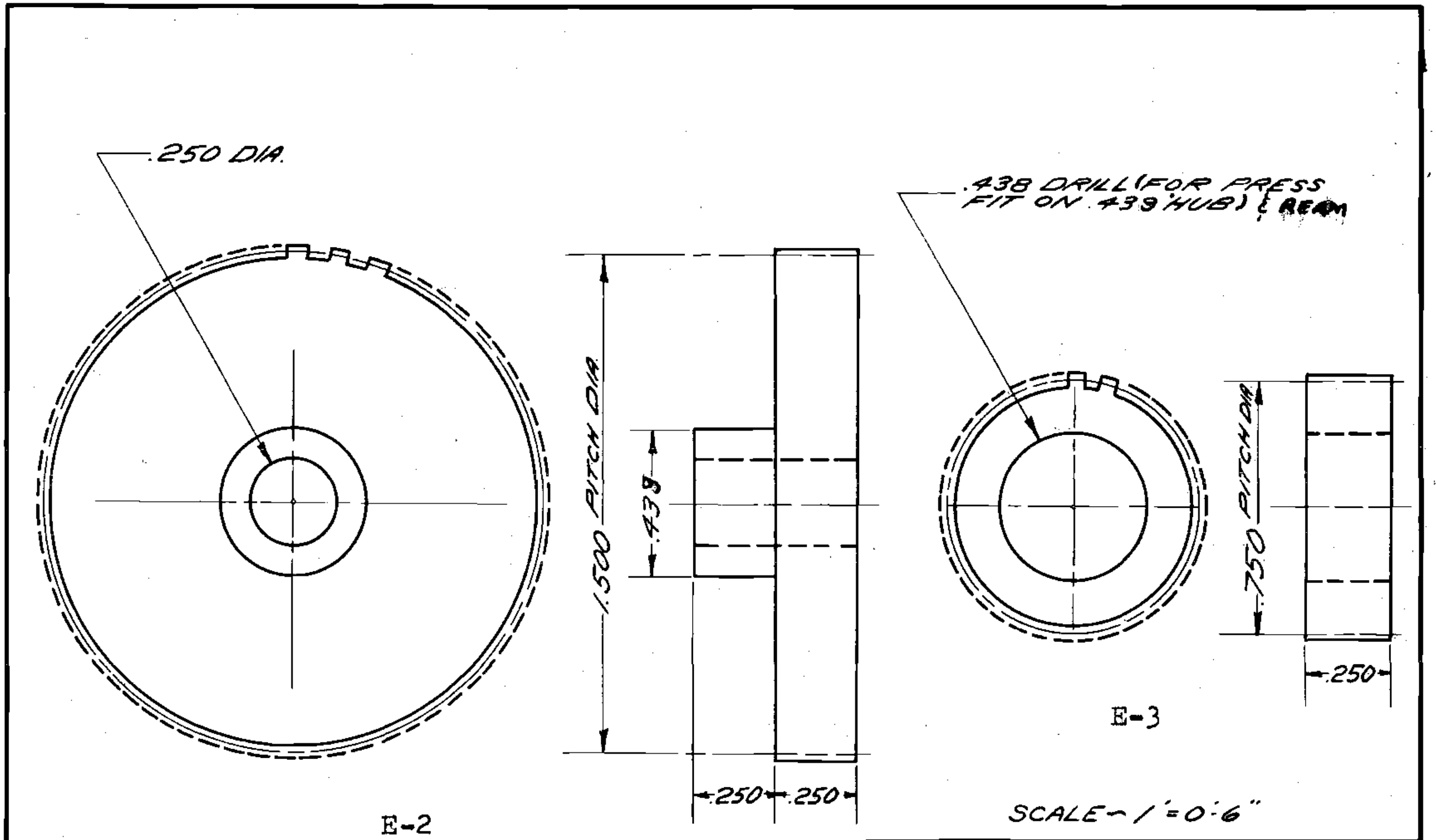


E-1

NOTE~ SPOKE STYLE

M & T TIMER
COUNTER MECHANISM

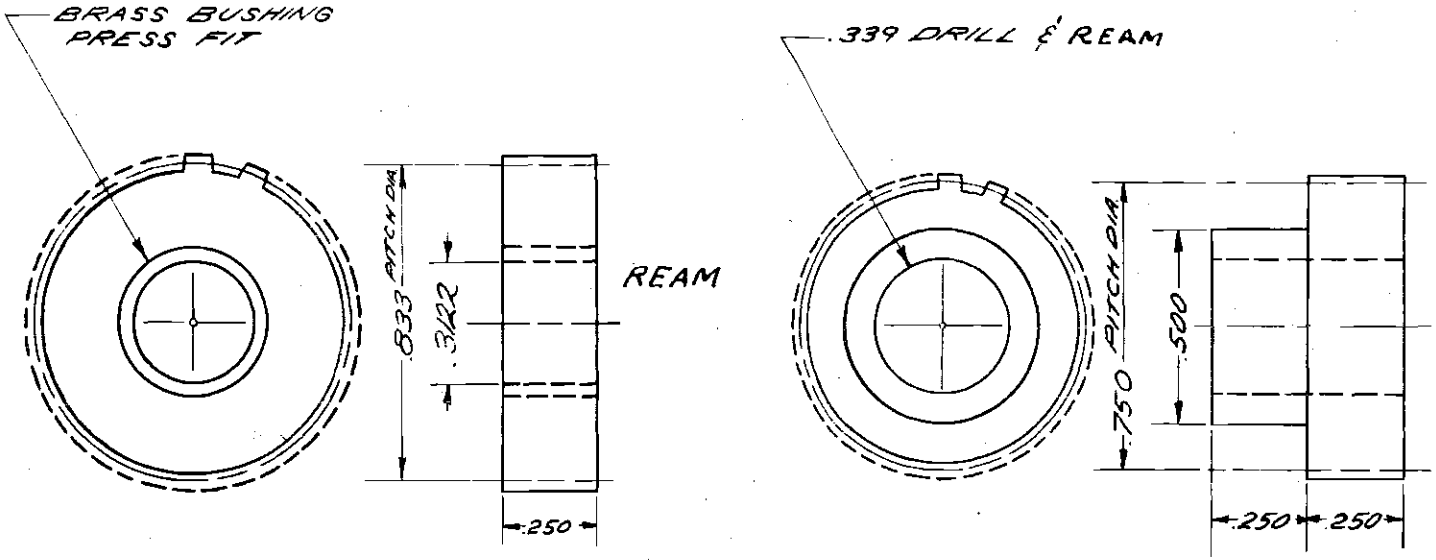
Part E-1 Dwg. No. 11



M & T TIMER

Counter Mechanism

Part E2, E3 Dwg. No. 10



E-4

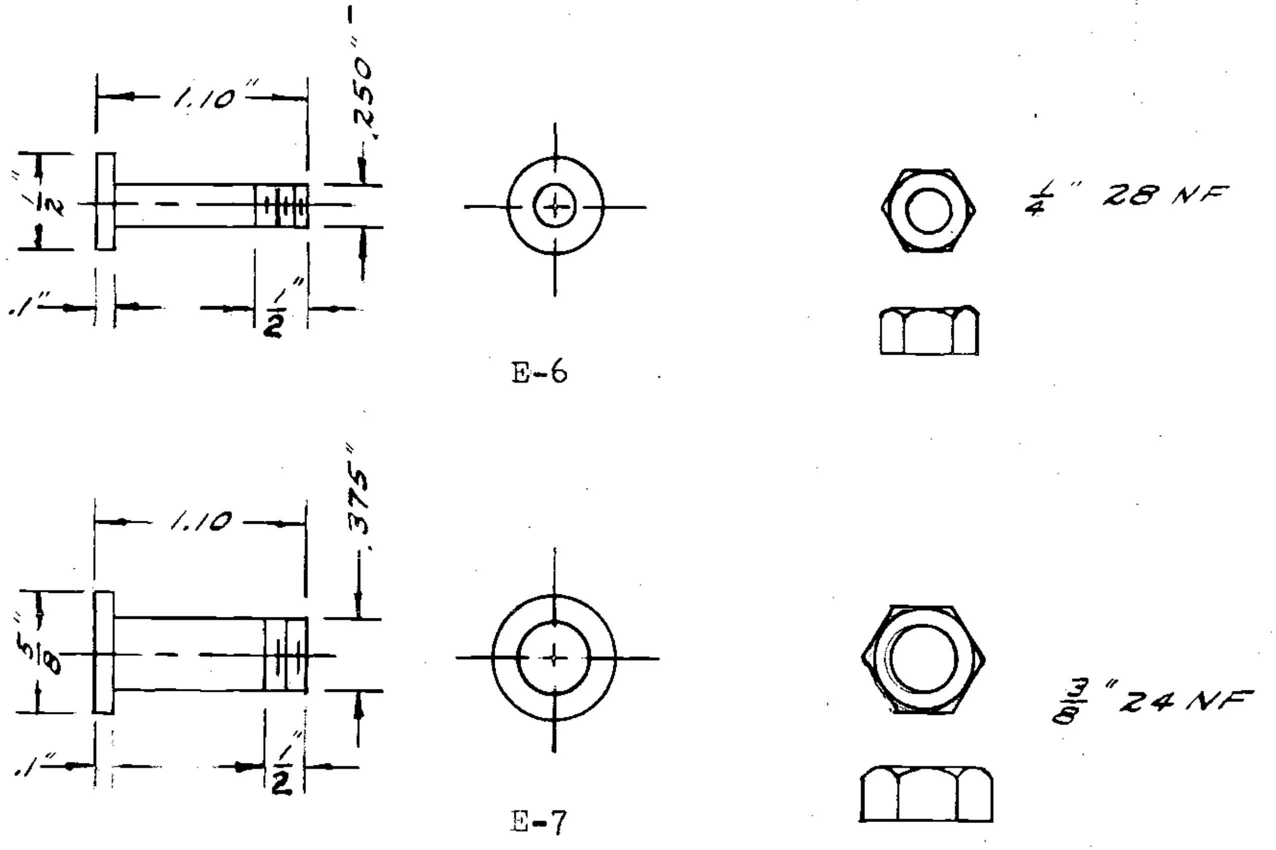
E-5

SCALE—1"=0'-6"

M & T TIMER

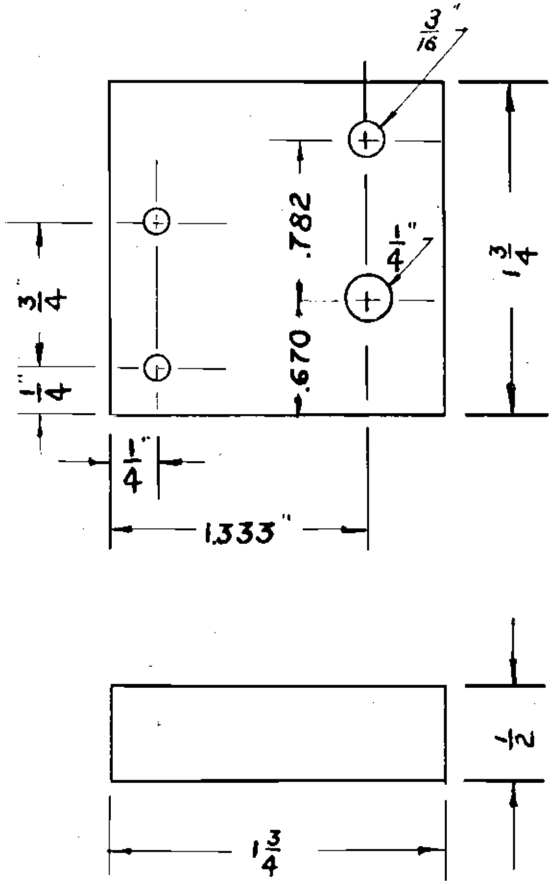
COUNTER MECHANISM

Part E4, E5, Dwg, No. 9

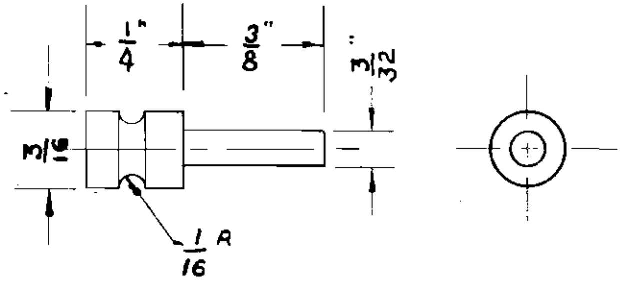


THREADS SAME AS NUTS

M & T TIMER	
COUNTER MECHANISM	
Part E6,E7	Dwg No. 7



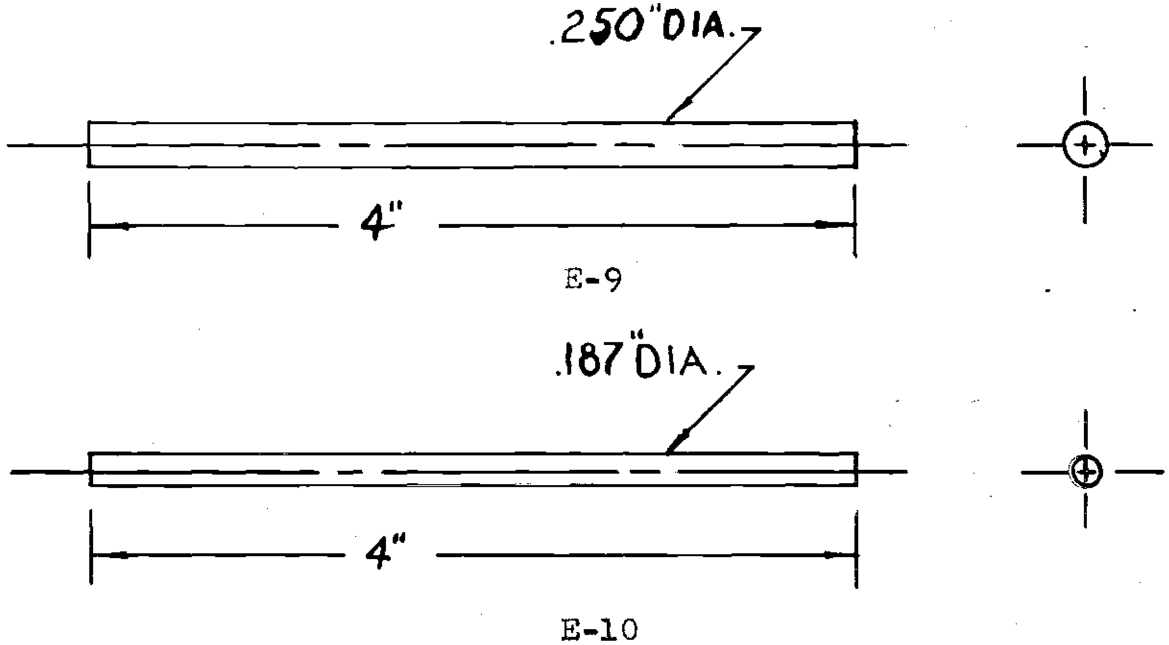
E-8



Two req'd

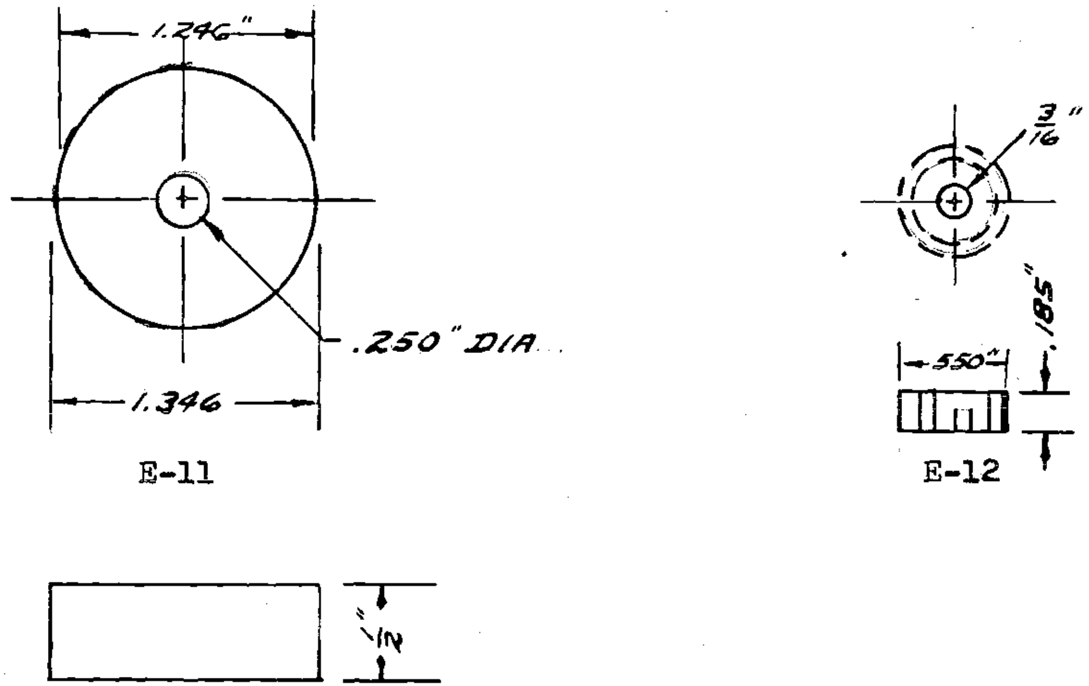
G-7

M & T TIMER
PAPER ADVANCE MECHANISM
Part E8,G7   Dwg. No. 30

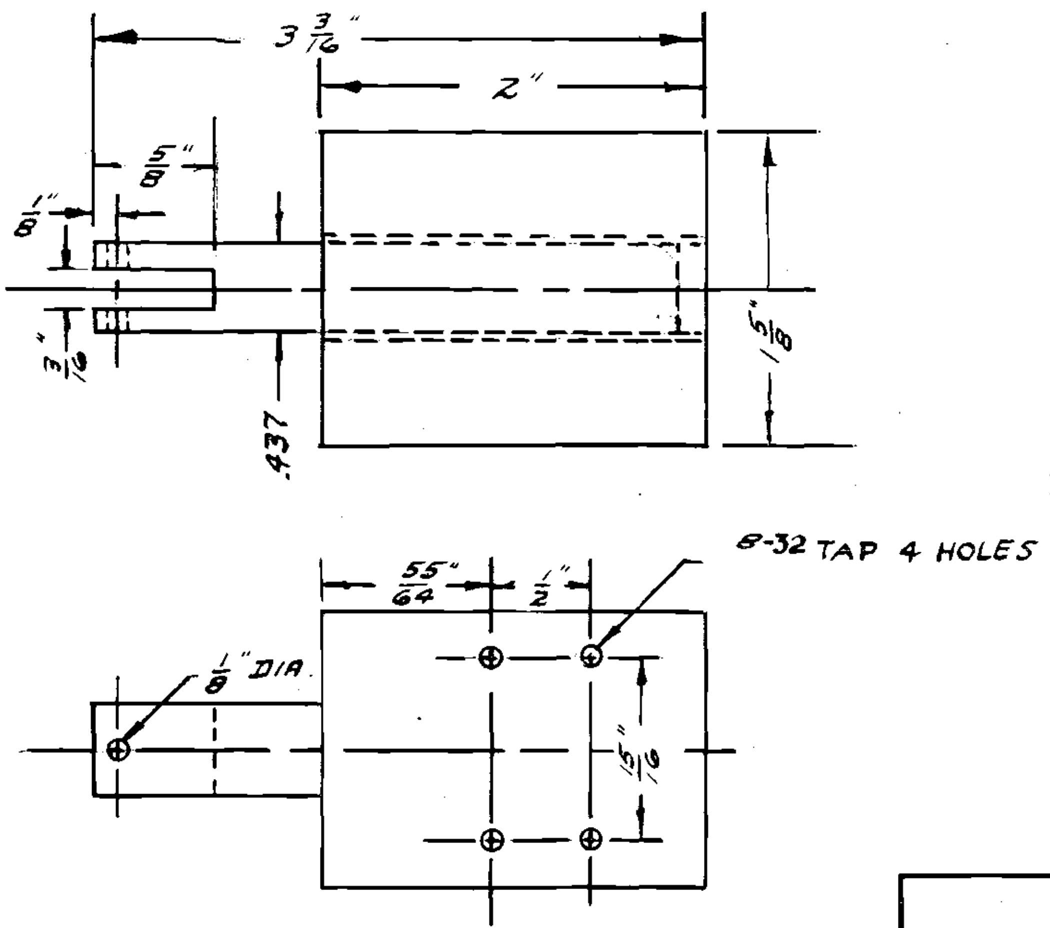


GRIND & CASE HARDEN

M & T TIMER
COUNTER MECHANISM
Part E9, E10 Dwg No. 8



M & T TIMER
COUNTER MECHANISM
Part E11, E12   Dwg No.12

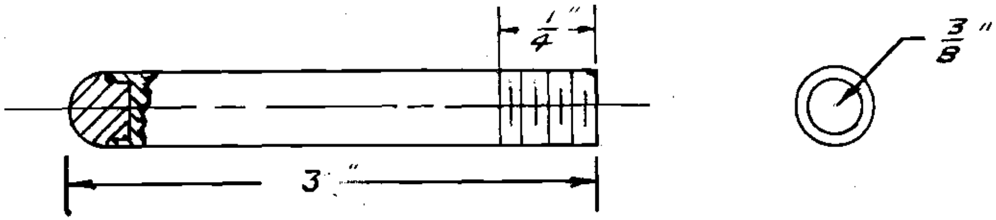


G-3

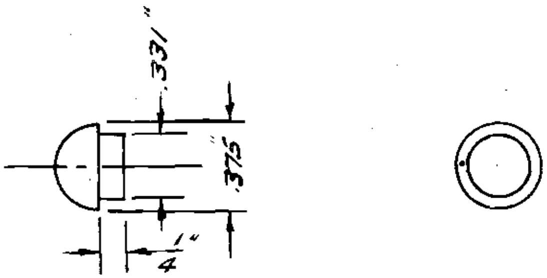
F-1

M & T TIMER

Part G-3, F-1 Dwg No. 26



F-2

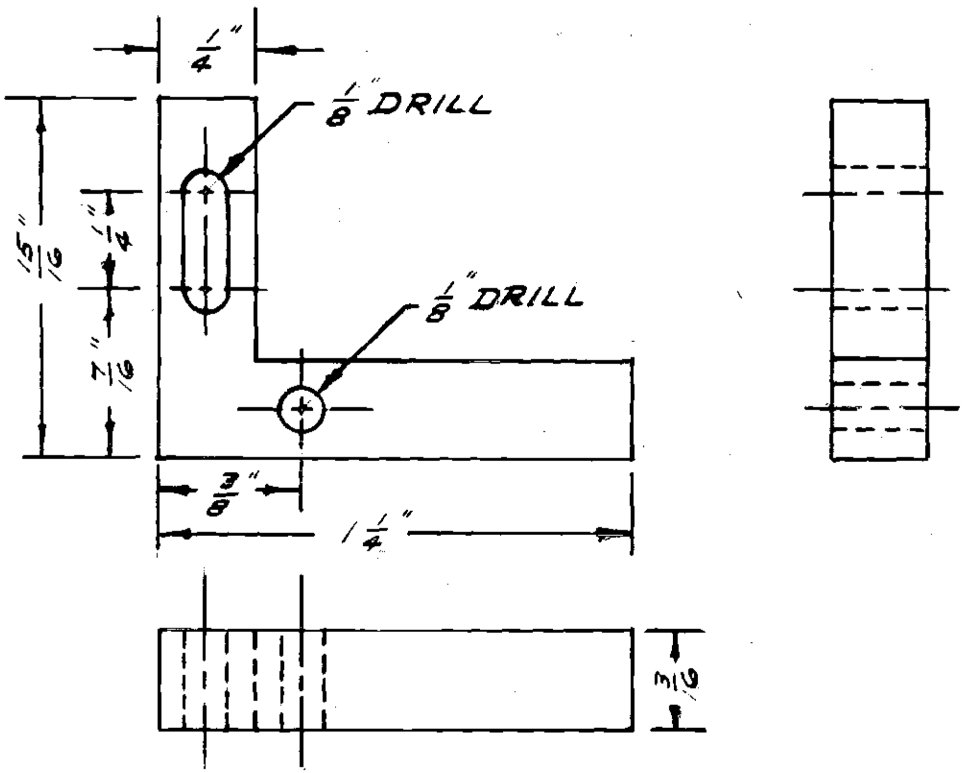


F-3

M & T TIMER

STRIKER

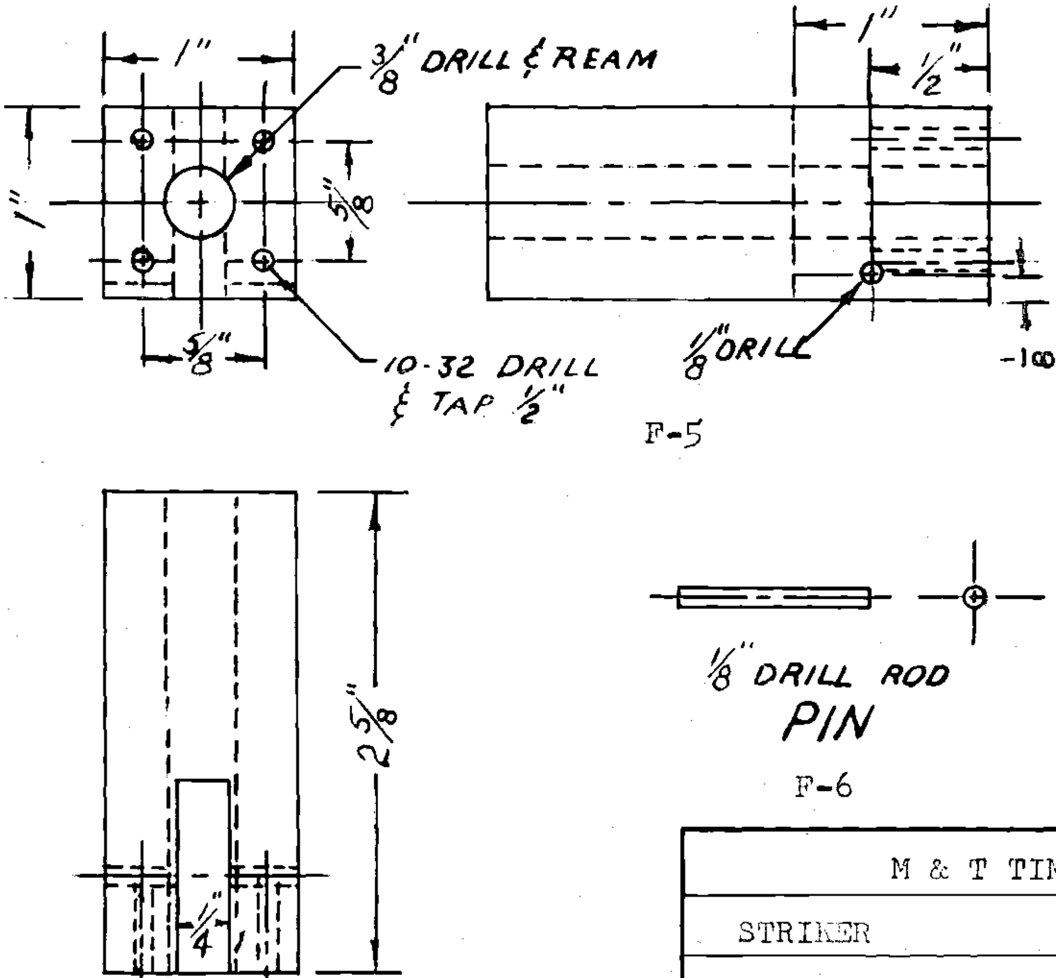
Part F2, F3, Dwg. No. 35



F-4

SCALE 1" = 0'-6"

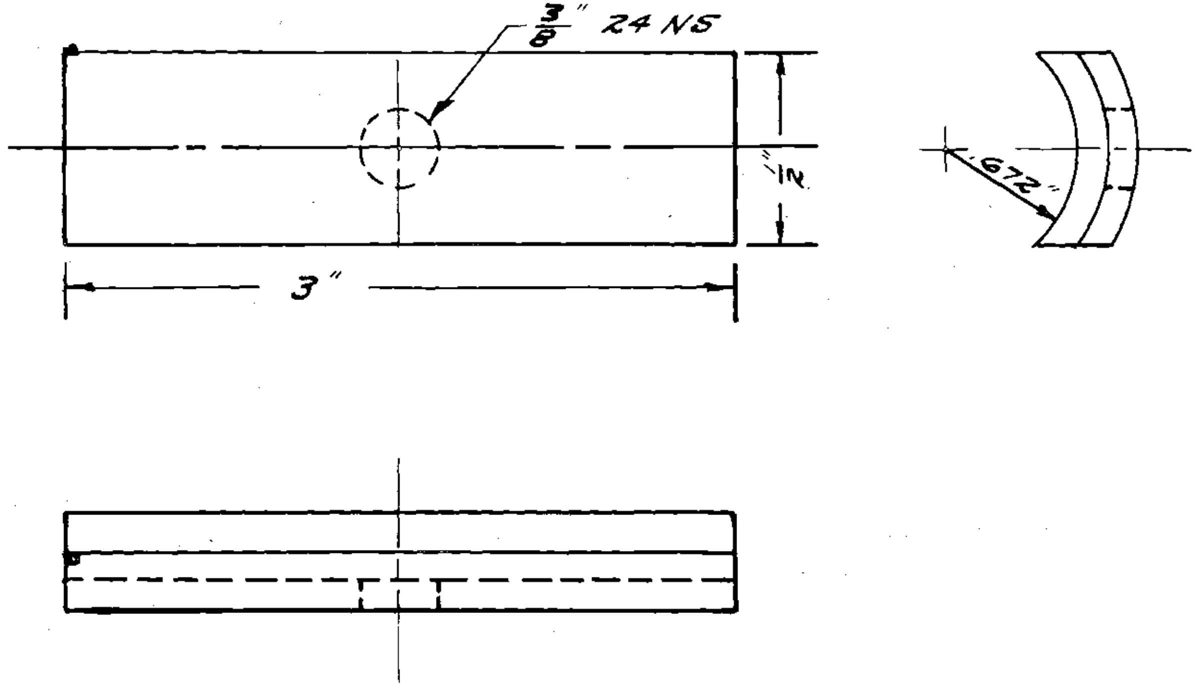
M & T TIMER	
STRIKER	
Part F-4	Dwg. No. 36



F-5

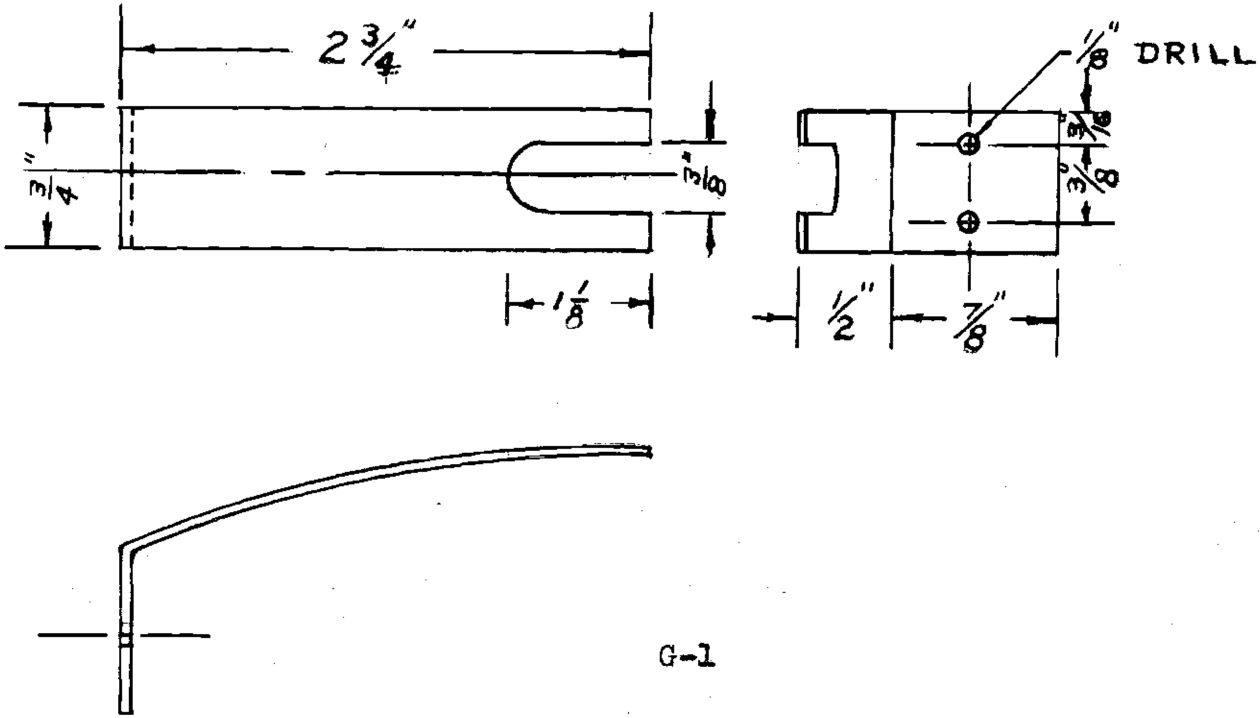
F-6

M & T TIMER
STRIKER
Part F5, F6, Dwg. No. 37



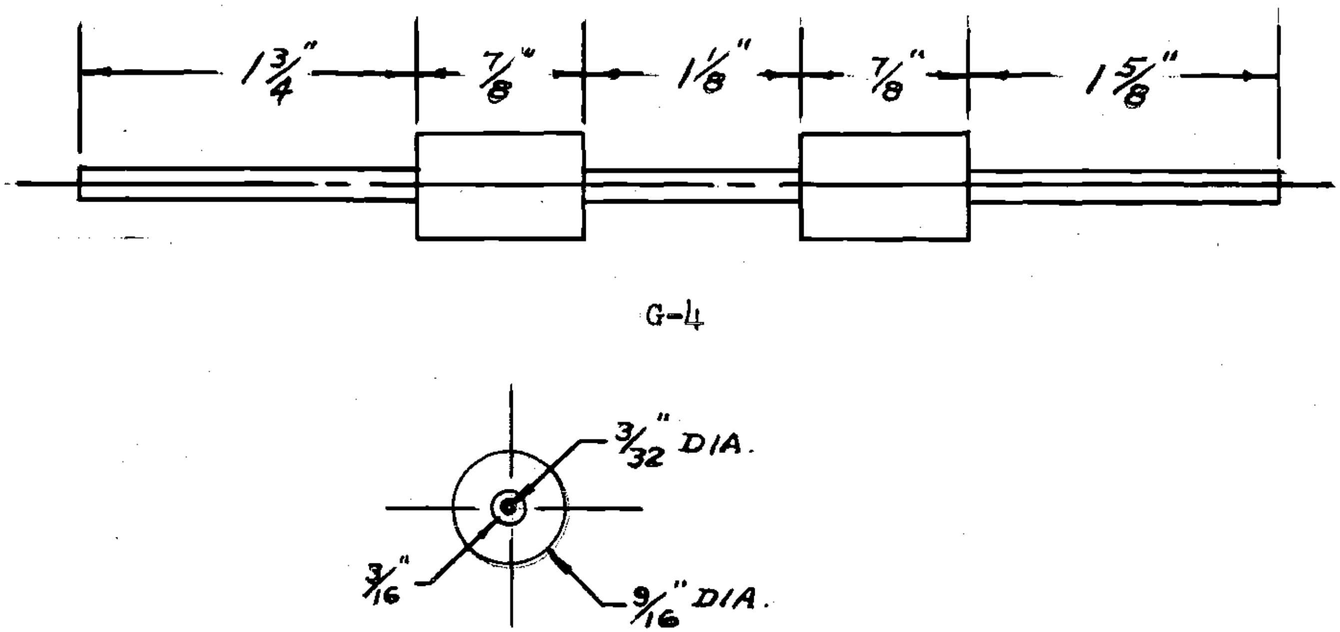
F-7

M & T TIMER
STRIKER
Part F-7 Dwg. No. 38

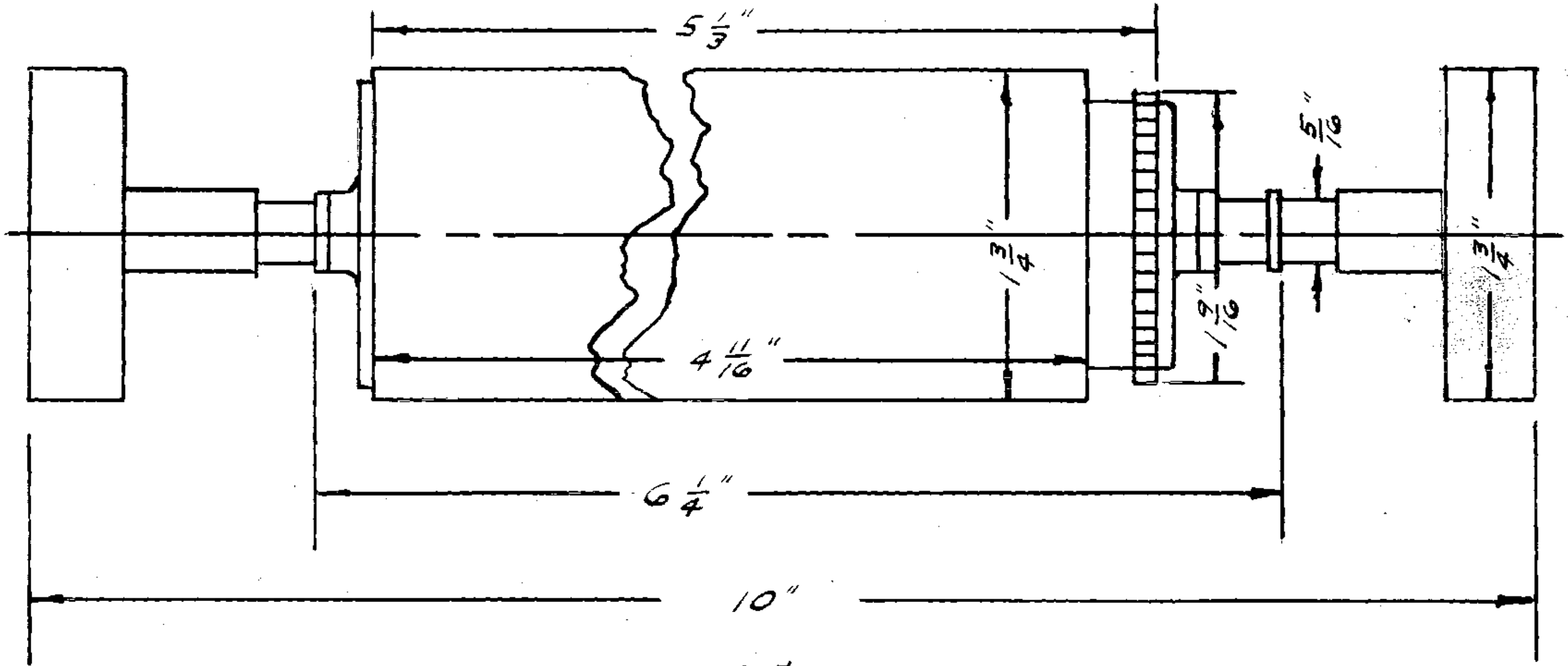


G-1

M & T TIMER	
PAPER ADVANCE MECHANISM	
Part G-1	Dwg No. 25

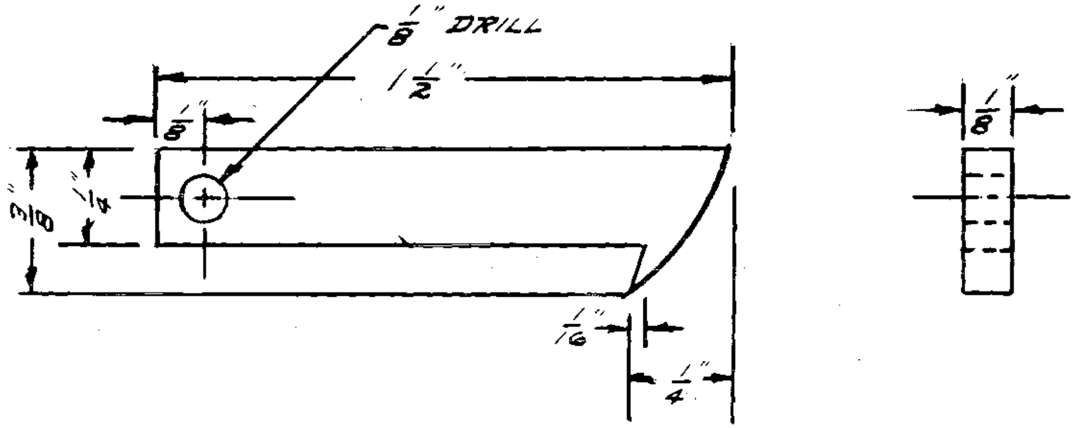


M & T TIMER	
PAPER ADVANCE MECHANISM	
Part G-4	Dwg No. 27



G-5

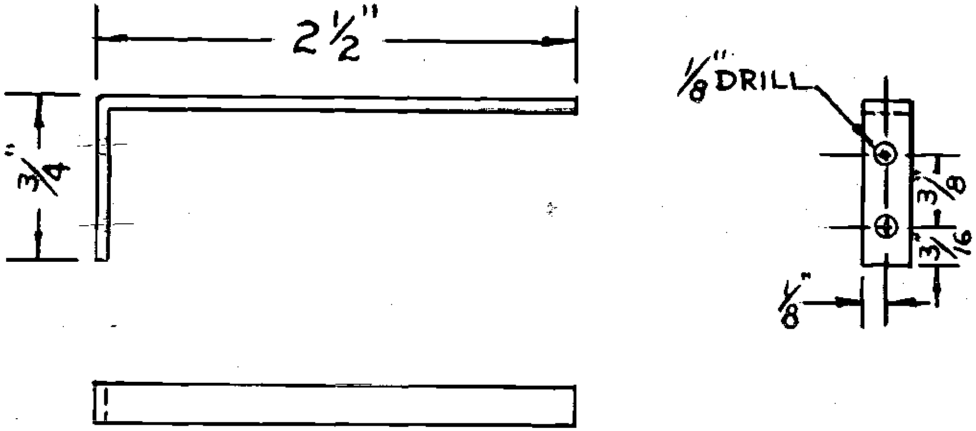
M & T TIMER
PAPER ADVANCE MECHANISM
Part G-5 Dwg No. 28



G-6

SCALE 1" = 0'-6"

M & T TIMER
PAPER ADVANCE MECHANISM
Part G-6 Dwg No. 29

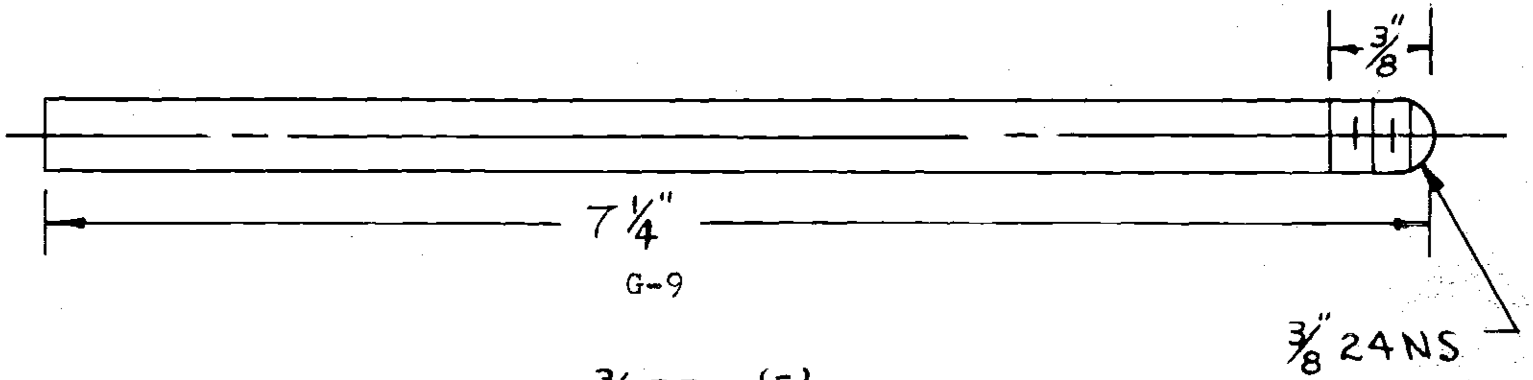


G-8

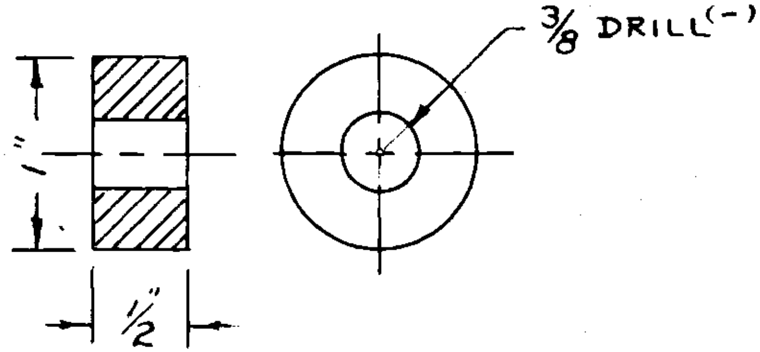
M & T TIMER

PAPER ADVANCE MECHANISM

Part G-8 Dwg. No. 31

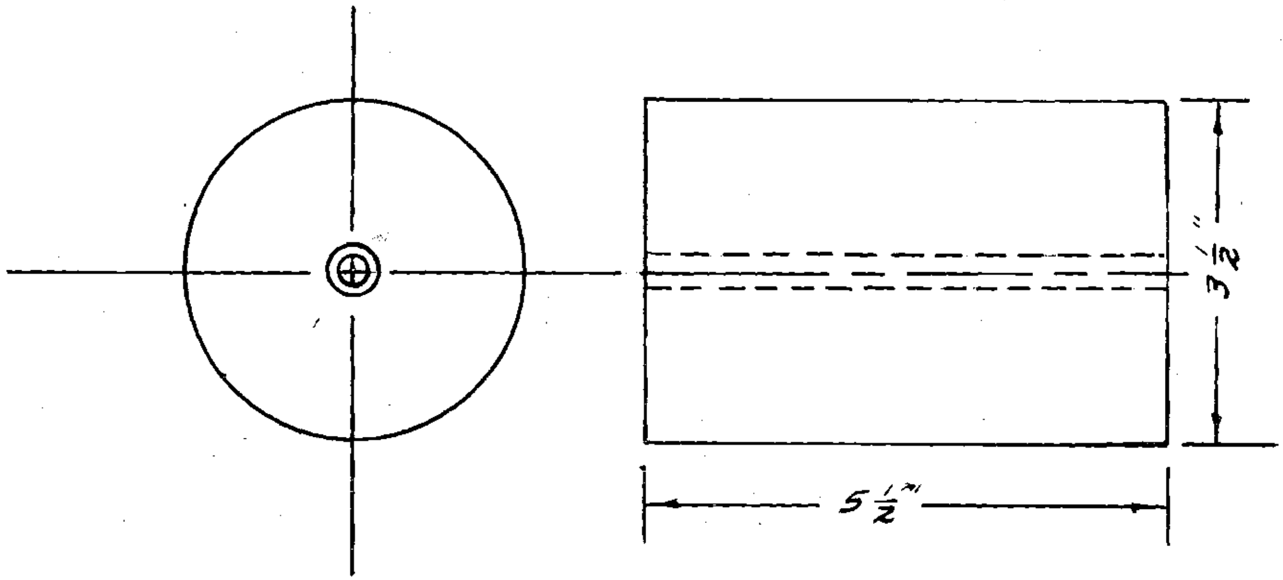


G-9



G-10

M & T TIMER
PAPER ADVANCE MECHANISM
Part G9, G10, Dwg. No. 32



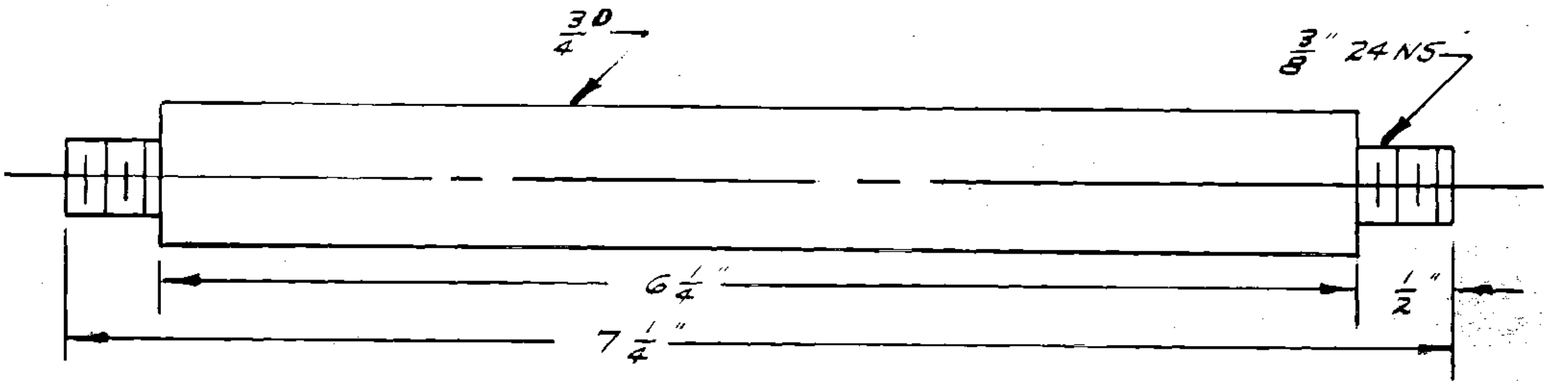
G-11

SCALE 1'=2'-0"

M & T TIMER

PAPER ADVANCE MECHANISM

Part G-11 Dwg. No. 33

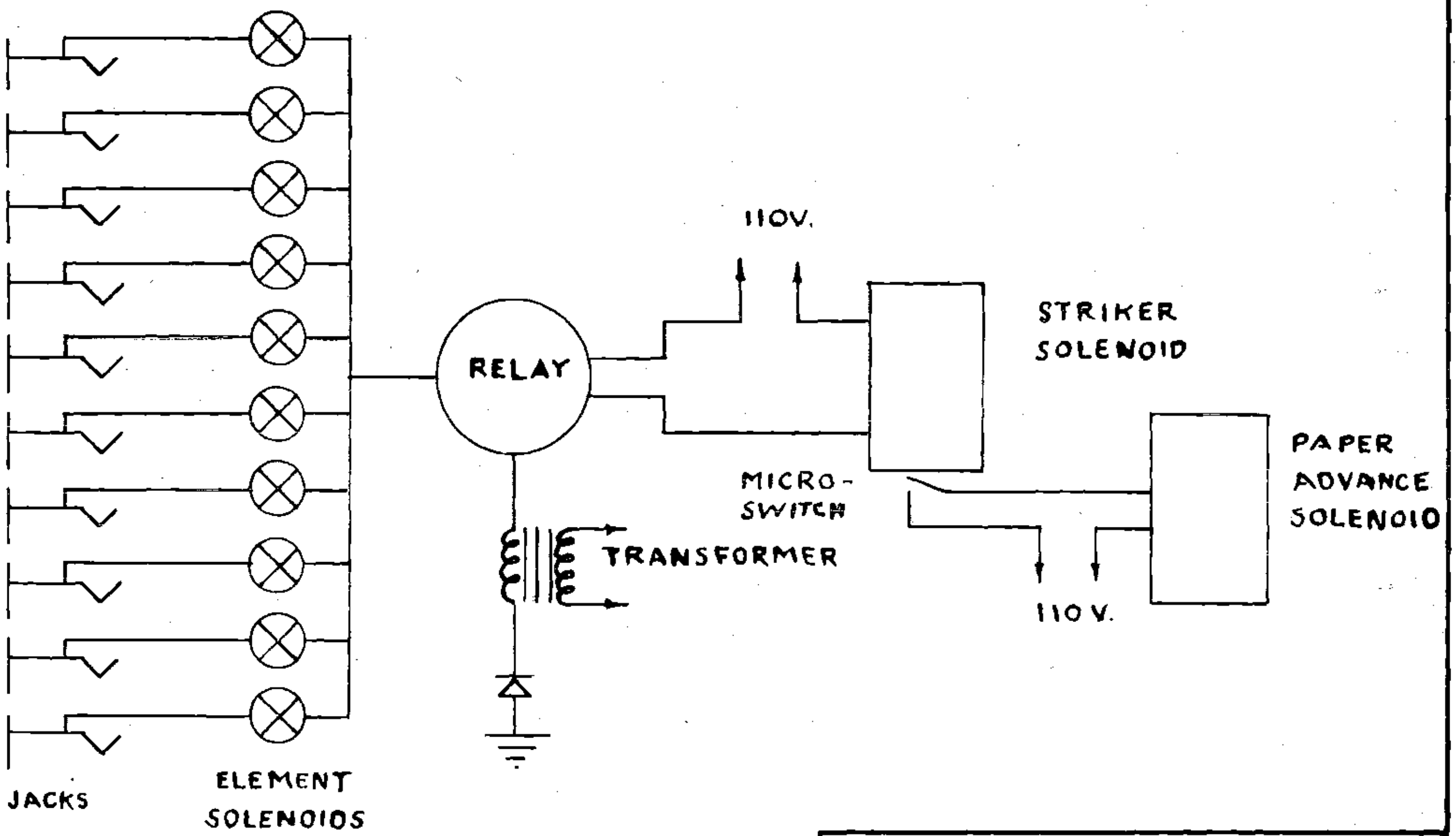


G-12

M & T TIMER

Paper Advance Mechanism

Part G-12 Dwg No. 24



M & T TIMER

CIRCUIT

Part C1, C2, Dwg. No. 34

PARTS LIST

FRAME

Part No.	Drawing No.	Material	Required	Page No.	Remarks
A-3	6	1/4 Aluminum Flat Stock	1	57	Front Side, Drill as shown
A-2	5	1/4 Aluminum Flat Stock	1	56	Back Side, Drill as shown
A-1	4	1/2 Aluminum Flat Stock	1	55	Botton, Drill as shown

ELECTRICAL

Part No.	Drawing No.	Material	Required	Page No.	Remarks
B-1	22		1	58	6V D.C. Relay, Guardian No. 200, SPMBB
B-2	23		1	59	1/75 HP, 1800 RPM Synchronous, 110V 60 Cycle A.C. Bodine Electric Co., Sleeve Bearings
B-3			1		Transformer, 12 Volt, Thordarson, T-21F14 B.A.H.
B-4			1		Full Wave Soleminium Rectifier, 6RS41CHB1 General Electric Co.

PARTS LIST - Continued

WIRING

Part No.	Drawing No.	Material	Required	Page No.	Remarks
C-1		No. 18 Single Strand Cloth Covered Hook Up Wire			Wiring Diagram for all 12 Volt Circuits
C-2		No. 14 Double Strand Rubber Covered Stranded Cable			Wiring Diagram for all 110-Volt Circuits

ELEMENT MECHANISM

Part No.	Drawing No.	Material	Required	Page No.	Remarks
D-1	14	Aluminum .102" Sheet Stock	5	60	Mounting for Element Solenoid, Cut Drill and Bend as shown
D-2	16		10	61	3/8" Phone Jack
D-3	20		10	62	6V D.C. Relay from Pinball Machine, Cut and Drill as shown
D-4	18	Steel and Rubber	1	63	Element Platten, Cut, Drill and Bend Brace, Vulcanize Rubber to Base
D-5	19	Aluminum	1	64	Element Type Bar Holder, Mill, Drill & Tap as shown

PARTS LIST - Continued

ELEMENT MECHANISM

Part No.	Drawing No.	Material	Required	Page No.	Remarks
D-6	15	Aluminum	1	65	Element Cover Plate, Cut and Drill as shown
D-7	19	1/8" Drill Rod	1	64	Pin Element Cams, Cut as shown
D-8	17	18 Gage Brass Stock	11	66	Element Cam Spacer, Cut and Drill as shown
D-9	17	11 Gage Carbon Steel	5	66	Element Cams, Cut and Drill as shown
D-10	17	11 Gage Carbon Steel	5	66	Element Cams, Cut and Drill as shown
D-11	21	.06" Diameter No. R Monel Wire	10	67	Element Pull Rods, Cut and Bend as shown
D-12			1		Element Type Bar, Victor Adding Machine, or any substitute, Cut to Fit

PARTS LIST - Continued

COUNTER MECHANISM

Part No.	Drawing No.	Material	Required	Page No.	Remarks
E-1	11	Brass	1	68	24P 72 Teeth 1/4", Boston Gear, Tolerance .0005"
E-2	10	Brass	1	69	24P 36 Teeth 1/4" Fact, Boston Gear, Machine as shown, Tolerance .0005"
E-3	10	Steel	1	69	24P 18 Teeth 1/4" Face, Boston Gear, Machine as shown , Tolerance .0005"
E-4	9	Steel	1	70	24P 20 Teeth 1/4" Face, Boston Gear, Machine as shown, Tolerance .0005"
E-5	9	Brass	1	70	24P 18 Teeth 1/4" Face, Boston Gear, Machine as shown, Tolerance .0005"
E-6	7	Carbon Steel	1	71	Shaft for Gear, Machine as shown, Case Harden and Grind Tolerance .0005"
E-7	7	Carbon Steel	1	71	Shaft for Gear, Machine as shown, Case Harden and Grind Tolerance .0005"
E-8	30	Aluminum	1	72	Counter Shaft Holder, .001" Mill and Drill as shown

PARTS LIST - Continued

COUNTER MECHANISM

Part No.	Drawing No.	Material	Required	Page No.	Remarks
E-9	8	1/4" Drill Rod	1	73	Counter Shaft, Cut as shown, Set with Center Punch
E-10	8	3/16" Drill Rod	1	73	Pinion Shaft, Cut as shown, Set with Center Punch
E-11	12		6	74	Type Wheel, 0-10 Numerals (one wheel has hub cut shown for press fit in .339 hole for driver gear. Original teeth on type wheel is removed.)
E-12	12		5	74	Counter Pinion Gear Productometer.
E-13	13		5		Washers, Counter, Not shown Productometer

STRIKER MECHANISM

Part No.	Drawing No.	Material	Required	Page No.	Remarks
F-1	26		1	75	Striker Solenoid, Guardian No. 4 A.C. 110 Volts
F-2	35	3/8", .022", 61S-T6	1	76	Striker Rod, Cut and Tap as shown

PARTS LIST - Continued

STRIKER MECHANISM

Part No.	Drawing No.	Material	Required	Page No.	Remarks
F-3	35	3/8" Drill Rod	1	76	Machine as shown
F-4	36	3/16" Steel Flat Stock	1	77	Striker Cam, Cut, Drill and Route as shown
F-5	37	1" Aluminum Square Stock	1	78	Striker Guide, Drill, Tap, and Mill as shown
F-6	37	1/8" Drill Rod	1	78	Striker Cam Pin, Cut as shown
F-7	38	18 Gage Sheet Steel and Rubber	1	79	Striker Platten, Cut, Drill, Tap and Vulcanize Rubber as shown
F-8		1/8" Drill Rod	1		Pin Solenoid, .437" long, Set with Center Punch, Not shown

PAPER ADVANCE MECHANISM

Part No.	Drawing No.	Material	Required	Page No.	Remarks
G-1	25	Spring Steel 18 Gage	2	80	Cut and Bend as shown (J. M. Tull, Carbon Steel Can Be Substituted)
G-2	16		1	61	Micro-switch Ml 1/4" x 3/4" x 1 S.P.D.T.

PARTS LIST - Continued

STRIKER MECHANISM

Part No.	Drawing No.	Material	Required	Page No.	Remarks
G-3	26		1	75	Solenoid, Guardian, No. 4 A.C. 110 Volts
G-4	27		1	81	Smith and Corona Typewriter Paper Pressure Roll 9/16" O.D., 6-1/4" Long, Remove Two Rubber Rolls
G-5	28		1	82	Smith and Corona Platten, 1-3/4" x 10", Cut to Length and Reassemble Paper Advance Pawl
G-6	29	1/8" Brass Stock	1	83	Machine as shown
G-7	30	3/16" Drill Rod	2	72	Pin Paper Pressure Roll Turn as shown Case Harden and Grind
G-8	31	18 Gage Spring Steel	1	84	Platten Ratchet Spring Cut Drill and Bend as shown
G-9	32	3/8" Drill Rod	1	85	Cut and Thread as shown
G-10	32	1" Aluminum Rod	1	85	Cut and Drill as shown
G-11	33	Single Paper With Carbon		86	5-1/2" x 3-1/2" Roll, Paper

PARTS LIST - Continued

PAPER ADVANCE MECHANISM

Part No.	Drawing No.	Material	Required	Page No.	Remarks
G-12	24	3/4" Aluminum Rod	1	87	Paper, Guide Turn and Thread as shown
G-13		Spring Steel	1		Pawl Spring, 3/4" Diameter hole, 2 oz. pressure radial thrust not shown
G-14		Spring Steel	1		Solenoid Spring 3/8" Diameter tapered 1" long, 3 oz. compression spring, not shown
G-15		1/8" Drill Rod	2		Pin solenoid 5/8" long, Not shown, set with center punch
		SCREWS			
H-1		8-32 3/4" long	8		
H-2		10-32 3/4" long	4		
H-3		6-32 3/4" long	4		
H-4		10-32 1/2" long	4		
H-5		1/8-40NS 1/2" long	26		

PARTS LIST - Contined

NUTS

Part No.	Drawing No.	Material	Required	Page No.	Remarks
I-1		1/4 28NF 1/4 Hex Head Nut	1		
I-2		3/8" 24NS 1/4 Hex Head Nut	3		

BIBLIOGRAPHY

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(Literature Cited)

(1) Barnes, Ralph M. and Williams, E. D., "The Automatic Time Recorder," Modern Management, V. 9, May '49, p. 4.

(2) Lockhart, A., "A Survey of Devices Used in Measuring Short Time Intervals," American Association Health Physical Education and Recreation, V. Q12, December '41, p. 763.

(3) Lockhart, A., "A Survey of Devices Used in Measuring Short Time Intervals," American Association Health Physical Education and Recreation, V. Q12, December '41, p. 763.

(4) Lazarus, I. P., "The Nature of Stop Watch Time Study Errors," Advanced Management, V. 15, May '50, p. 15.

(5) Walker, E. A., "An Instrument for Measurement of Short Intervals of Time," Franklin Institute Journal, V. 231, April '41, p. 373-9.

(6) Walker, E. A., "An Instrument for Measurement of Short Intervals of Time," Franklin Institute Journal, V. 231, April '41, p. 373-9.

(7) Steiner, L. A., "On Timing Devices Merrits and Limitations of Three Types," Chemical Age (London), V. 54, April '46, p. 453-7.

(8) Decker, J., "How Many Hours A Day Do Your Machines Work," Factory and Industrial Management, V. 83, November '32, p. 422-4.

(9) Lockhart, A., "A Survey of Devices Used in Measuring Short Time Intervals," American Association Health Physical Education and Recreation, V. Q12, December '41, p. 763.

(10) Barnes, Ralph M. and Williams, E. D., "The Automatic Time Recorder," Modern Management, V. 9, May '49, p. 4.

(11) Jones, Dale, "And Now; Recorded Time Studies Dictated Into Magnetic Wire Recorder," Factory Management and Maintenance, V. 108, March '50, p. 126.

(12) Jones, Dale, "And Now; Recorded Time Studies Dictated Into Magnetic Wire Recorder," Factory Management and Maintenance, V. 108, March '50, p. 126.

(13) ________, "How Machine Made Time Studies," Factory Management and Maintenance, V. 97, N. 5, May '39, p. 66.

(14) Barnes, Ralph M. and Williams, E. D., "The Automatic Time Recorder," Modern Management, V. 9, May '49, p. 4.

OTHER REFERENCES

________, "A Precision Microtiming Zarem Camera," Production Engineering, V. 19, November '47, pp. 147-8.

Emerick, R. S., "Spiral Chronograph for Measurement of Single Millisecond Time Intervals with Microsecond Accuracy," Review Scientific Instruments, V. 18, March '47, pp. 150-7.

Jordan, A. H. and Vogelsang, C. A., "Applications of Multiple--Printing Recorders," Instruments, V. 19, N. 6, July '46, pp. 339-41.

Jupe, J. H., "Electronic Watch Timer," Electronics, V. 22, November '49, p. 197.

Moisech, "Psychotechnik Des Zeitnehnens in der Werkstatt; Vergleich versehiedener Zeitmessinstruments und Zeitmessverfahren," Industrielle Psychotechnik, V. 4, N. 4, April '22, pp. 97-121.

Muller, R. H., "American Apparatus, Instruments, and Instrumentation; Time Measurements," Industrial and Engineering Chemistry Analytical Ed. 12, October 15, '40, p. 577-8.

Philpott, S. F., Modern Electric Clocks, Ed. 4, New York: Pittman Publishing Corporation, 1949.

Rawlings, Arthur L., Science of Clocks and Watches, Ed. 2, New York: Pittman Publishing Corporation, 1948.

Smith, G. F., Laboratory Timing Clocks, Chemical Society Journal, March 1944, p. 113.

Smith, R. W., Testing of Measuring Equipment Handbook, U. S. National Bureau of Standards, 1951.

Williams, H. H., "Comparison of Time Measuring Mechanisms," Taylor Society Bulletin, V. 16, August '31, pp. 173-75.

Wolfe, A. E., Jr., and Steele, F. G., "Direct Reading Electronic Clock Used To Measure Time Intervals Between Two Operations or as a Predetermined Clock Counter," Electronics, V. 22, December '49, pp. 75-7.