DESIGN OF ELECTRICAL DATA
RECORDING AND READING MECHANISM

by

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I. INTRODUCTION

In the field of computing and tabulating machines it has been for many years the practice to record data of various sorts by means of holes punched in cards, the holes being arranged according to some scheme of coding to represent the desired information. The widely known Hollerith and Pierce systems are typical examples. In both of these systems round or rectangular holes are punched mechanically in cards, and the information thus recorded is later read by passing the cards between sets of brushes which are held open by the cards except where there are holes, at which points electrical contacts are made.

The present work was undertaken in conjunction with the development of a high-speed computing machine. The problem may be stated briefly as follows: In order to realize to the fullest extent the high-speed capabilities of the computing machine proper, it is necessary to record and read numbers on cards at rates of the order of 60 holes per second. This seems plainly beyond the limits of practicability in so far as the usual mechanical methods are concerned; hence, the method to be described was developed to meet this need.

The new method consists in punching holes by means of electrical discharges through the cards, and then in reading by means of weaker discharges which cannot penetrate the cards except at the points already punched.

During the course of the development the method was thought to be entirely new; however, after the major part of the work had been completed, several patents relating to the basic method were found. Since these had no influence on the present work, they are discussed briefly in the appendix only.

II. GENERAL DESIGN CONSIDERATIONS

As stated in the introduction, the basic principle of the new method of recording and reading data by a punched-card system is that of punching holes in cards with electrical discharges, and reading the cards with weaker discharges. In the computing machine for which the device described here is designed it is necessary for the cards to be both punched and read at a rate of about 60 holes per second while the cards are in continuous motion. The problem resolves itself into three main parts as follows: (a) the punching system, (b) the reading system, and (c) the mechanical apparatus for handling the cards. In this section of the thesis are discussed the general considerations governing the design of each of the above-mentioned components of the complete device.

First, however, it is necessary to say a word about the card material. Research on the most suitable kind of card material for the new method has not been completed. For the purpose of design it was assumed that card materials of the same general type as those in use with present tabulating machines would be used. This assumption appears valid since rough experiments with standard IBM cards show them to have reasonably good ratios of initial punching voltage to required reading voltage (hereafter called the read-back ratio), which is obviously a necessary property of the cards for the new system. Furthermore, such a material has good uniformity, possesses suitable mechanical properties for easy handling, and is economical.

A. The Punching Apparatus

The essentials of a punching system are shown in the block diagram of Fig. 1; they comprise a set of electrodes between which the card is passed, a source of high voltage, and means for controlling the application of the voltage in accordance with the incoming information. The requirements to be met by such a system may be stated as follows: (a) It must supply sufficient voltage to break down the card; (b) it must supply sufficient energy to burn a suitable hole in the paper; (c) it must be easily controlled; (d) it must be positive in action; and (e) it must be reasonably economical.

It is plain that the amount of voltage necessary to puncture a card depends primarily upon the card material, the card thickness, and the electrode shape. The general electrode shape, however, is determined by another consideration; fairly sharp points must be used in order to limit closely the region in which field strengths high enough to puncture the card exist. The only practical method of obtaining voltages of the order of several thousand volts is by transformer action, which was the means considered in this development.

The second requirement is less definite than the first, since the question must be asked, what is the size needed for a suitable hole? The answer is connected with the behavior of the card material and the sensitivity of the reading apparatus. For a given amount of energy one material may have a larger hole punched than another. On the other hand, the

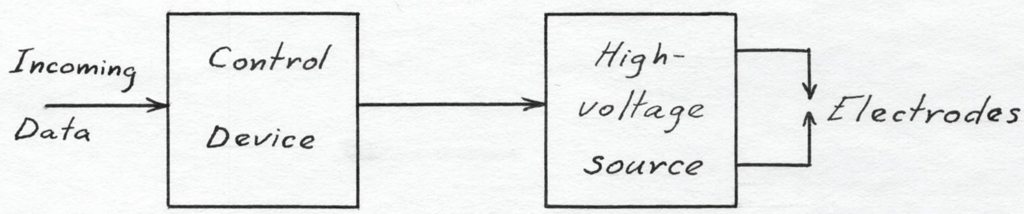

Figure 1

Basic punching system

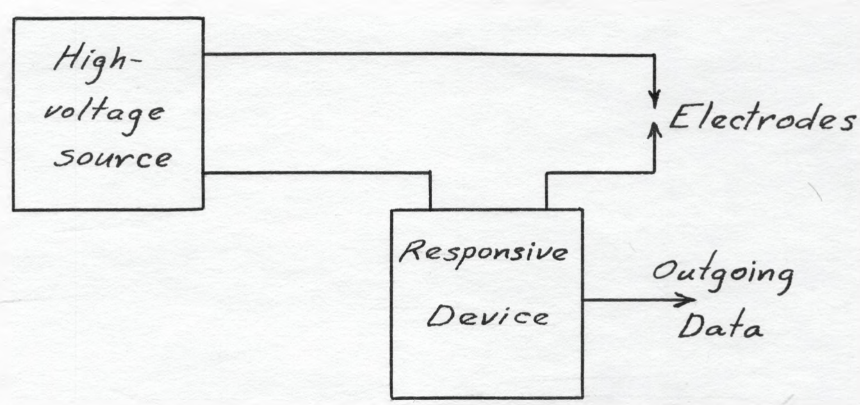

Figure 2

Basic reading system

greater the sensitivity obtainable in the reading apparatus, the smaller the holes and thus the smaller the energy which may be used. However, experiment shows that if the holes become too small, the read-back ratio increases. The whole matter, then, becomes one of compromise between the various aspects.

The requirement of ease of control, together with the high speed of operation desired and the fact that the control obtained from the calculating machine is in the form of low-voltage impulses, suggests at once that the most practical method of control is through the use of electron tubes.

Discussion of the requirement of reliability is hardly necessary, since it is obvious that if a hole were punched or omitted by accident, the result of a long series of computations might be seriously in error.

In the computing machine for which this system is designed, thirty punching electrode sets, each supplied by separate but identical punching systems, are necessary. Thus the question of economy becomes of much greater importance than it would if only one or two punching systems were needed. In fact this point largely governs the choice among three of the most practical punching systems, as will be seen later.

B. The Reading Apparatus

The basic components of a reading system are shown in the block diagram of Fig. 2. They are seen to consist of a pair of electrodes between which the cards are passed, a source of high voltage, and a device which responds to the reading impulses and passes them into the calculating machine. The requirements which must be met by the reading apparatus are as follows: (a) It must force a discharge through a spot which has been punched, but must be unable to punch a hole of its own accord; (b) it must be sensitive enough that large amounts of energy are not required; and (c) it must be reliable in action.

The reason for requirement (a) is plain; should a breakdown occur under the application of the reading voltage, the system would respond exactly as if a hole had been previously punched in that spot, and an error would result. The exact magnitude of the reading voltage required depends upon the same factors determining the punching voltage, and also to some extent upon the size of the holes if extremely small holes are being used. The shape of the electrodes in this case should be flat rather than sharply pointed, in order to make less critical the location of the holes.

With regard to the second requirement, the greater the sensitivity of the reading system, the less the energy needed in both the punching and the reading systems. The sensitivity must not be made too great, however, or the circuit may be affected adversely by stray fields in the room or by crosstalk from adjacent circuits.

The requirement of reliability of the reading system as a whole needs no particular discussion.

C. The Mechanical Apparatus

The mechanical apparatus needed for card handling may conceivably take many forms, but all must be basically the same. The components must include means for driving the cards in phase with the computing machine, means for starting the cards, and suitable supports for the electrodes. The chief requirements to be met by such an apparatus are simplicity and reliability. Because of the desirability of using different kinds of electrodes for punching and reading, two mechanisms are needed in the present machine; which, however, need differ only in the electrode assemblies.

III. EXPERIMENTAL INVESTIGATION OF VARIOUS CIRCUIT ARRANGEMENTS

In dealing with electrical circuits involving small amounts of power, the most expedient way of making progress is often by an intelligently pursued process of cut-and-try. This was the process employed in the investigation of punching and reading circuits. No attempt was made to obtain precise measurements; rather, interest was confined to orders of magnitude, since in any such apparatus as that under consideration large tolerances are always needed.

A. Punching Circuits

A number of different types of punching circuits were set up in the laboratory and tested. The circuits may be grouped into three basic types as follows: (a) The induction coil circuit, (b) the igniter circuit, and (c) the thyratron circuit. These will be discussed in turn.

1. Induction coil circuit.

The diagram of the induction coil punching circuit is shown in Fig. 3. This is perhaps the simplest and most obvious type of circuit. In it the direct current in the induction coil primary flows through the plate circuit of a vacuum tube. If the tube is suddenly blocked by decreasing its grid voltage, the plate current is interrupted almost instantaneously, and the induced voltages in the windings are very high; in fact, they are limited chiefly by the distributed capacitance of the coil. Thus, if the winding is properly designed, voltages of the order of several thousand volts are easily obtained at the electrodes.

A few tests of this circuit using various tube and transformer combinations soon showed that it is unsuited for high-speed punching unless tubes of considerably larger power capabilities than type 6L6 or similar types are used. Thus, while the circuit is theoretically sound, from an engineering standpoint it must be discarded as a high-speed punching circuit, because the required apparatus becomes too expensive and bulky.

2. Igniter circuit.

In Fig. 4 is shown the basic principle of the igniter circuit. This circuit gains its name from the fact that the high-voltage source is not required to furnish the entire punching current, but merely starts or ignites the discharge of a relatively low-voltage source. The main discharge circuit, although it need not have enough voltage to puncture the card, must still deliver about 1500 volts, which can be obtained practicably only by means of a transformer connected to the a-c mains. This has the advantage that no control over the main punching voltage is required, since the arcs extinguish automatically at the end of a cycle of the mains voltage. On the other hand, it requires that the entire operation of the

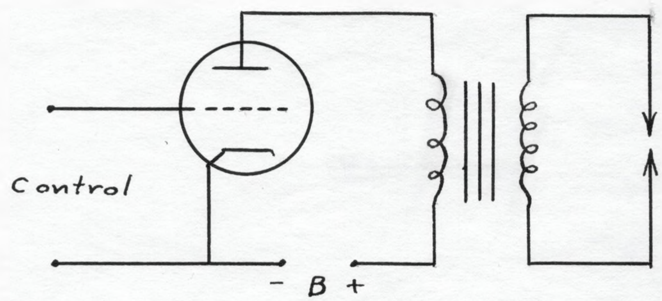

Figure 3

Induction coil punching circuit

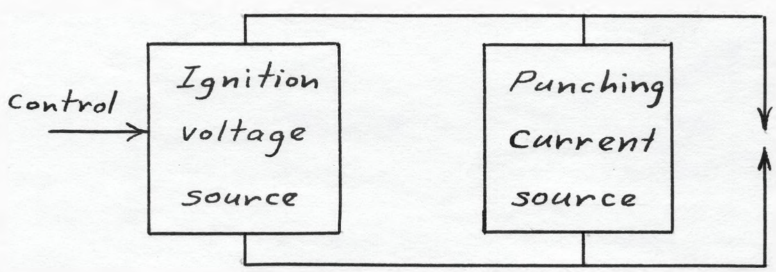

Figure 4

Basic igniter circuit

computing machine be synchronized with the line frequency; this, however, is no great disadvantage.

a. Series igniter. The circuit of Fig. 5 was set up to test the igniter principle. The first tube was merely a pulse sharpener controlled by the supply line, controlling in turn the igniter tube, a 6L6G. The plate circuit of the igniter tube in series with a 3000 volt 18 ma. neon tube transformer was supplied with current from the 110 volt d-c mains. The secondary of the igniter transformer was connected in series with the punching transformer secondary, an 866 mercury vapor rectifier, and the punching electrodes. The punching transformer delivered 1500 volts and was rated at ½ kw. The purpose of the rectifier tube was to obviate the possibility of re-striking the arc at the end of a punching cycle.

In operation a card was pulled between the electrodes at a speed of about one foot per second with the circuit punching on every positive half cycle. It was found that the circuit functioned according to theory, but considerable difficulty was experienced in securing sufficiently large holes. Further consideration of the circuit shows the reason for this. The secondary of the igniter transformer was necessarily of high impedance, since it was designed to deliver a high voltage and a low current; at the same time, it was in series with the punching transformer, so that the entire punching current had to flow through it. For this reason the circuit is disadvantageous.

b. Radio-frequency igniter. As a modification of the series igniter, a radio-frequency voltage from an oscillator was used as the ignition source, in order to eliminate the high impedance in the circuit. The method could be made to function, but it was discarded because of its inherent complexity.

c. Parallel igniter. In Fig. 6 is shown the circuit for parallel ignition. This circuit eliminates the objection to the series type, since the ignition and punching circuits are effectively separated, having only the circuit through the card in common. The experimental set-up used the same components as the series circuit, with the addition of the second mercury vapor rectifier. It is seen that the function of the rectifier T_1 was to permit the igniting voltage to reach the electrodes, and at the same time to prevent flow of a circulating current from the punching transformer which would saturate the core of the igniter transformer. The rectifier T_2 prevented the punching transformer from shunting the high-voltage igniting impulse, and aided in preventing saturation of the igniter transformer.

This circuit, as might be expected, performed more satisfactorily than the series type. The control was positive in action, and holes of satisfactory size could be punched in typical card materials. It is plain, moreover, that one punching transformer and two rectifiers could be used with a number of electrodes provided separate resistors R_1 and separate

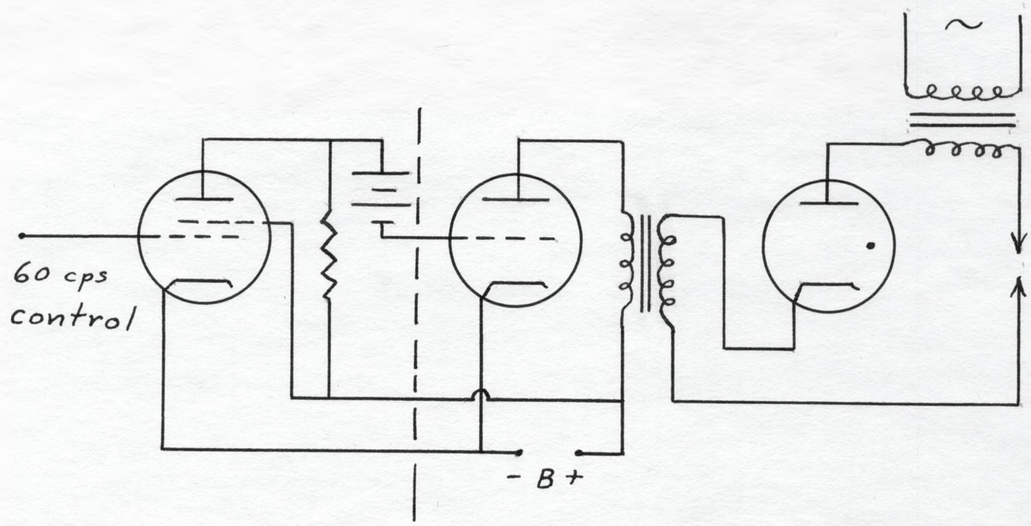

Figure 5

Series igniter circuit

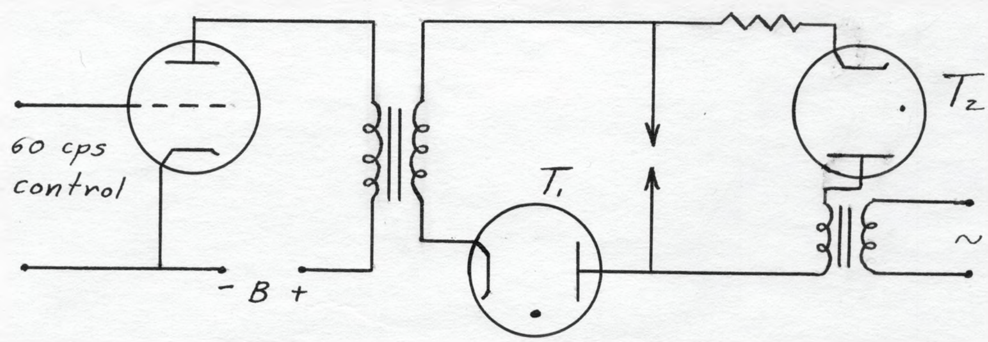

Figure 6

Parallel igniter circuit

igniter circuits were used. This circuit meets all of the requirements mentioned previously, except perhaps that of economy. This point will be discussed later.

3. Thyratron circuit.

The third method of punching consists in directly controlling a current from a high-voltage transformer by means of a thyratron either in the primary circuit or in the secondary circuit. The thyratron can only initiate a current flow, but because of the fact that alternating current is being supplied, arcs in the tube and in the card are automatically extinguished, as in the igniter method.

a. Secondary control. The diagram of Fig. 7 shows a punching circuit with the thyratron in the secondary of the transformer. The experimental set-up used a type FG-17 tube and a transformer with a peak voltage variable from 3000 to 5000 volts. Control was obtained by the same sort of arrangement as that shown in Fig. 5. The resistor R_1 was necessary to limit the current flow, since the transformer had a relatively low impedance, and neither the tube nor the arc possessed current-limiting properties.

Very satisfactory punching could be obtained with this circuit; sufficient voltage was obtainable and the energy put into the hole could be increased to any desired amount by merely adjusting R_1. However, perfect reliability could not be obtained until the dotted resistor R_2 was connected across the electrodes. The purpose of this resistor, which had a value of 2 megohms, was to make definite the time of firing the tube. Without it, the voltage distribution was determined by the leakage resistances and stray capacitances across the tube and electrodes, and there was no assurance that firing could take place. With the resistor, the entire transformer voltage was impressed across the tube at the instant of firing. Immediately after firing, the transformer voltage (less a few volts tube drop) became impressed across the resistor, and thus across the electrodes. This caused an arc to form in the card, which effectively removed the resistor from the circuit for the duration of the punching cycle.

A slight modification of this circuit which was tested consisted in connecting a 2 megohm resistor, R_3, directly across the thyratron. The effect of this was to reduce by one half the maximum voltage ever appearing across the tube without affecting the amount of voltage available for breaking down the card material. The additional resistor had no effect on the circuit once the tube had fired. The only improvement which this circuit offers is that of lowering the voltage rating required of the thyratron.

<u>b. Primary control.</u> The second type of circuit using thyratrons is shown in Fig. 8. In this a low-voltage, high current thyratron is placed in the primary circuit of the punching transformer. At first sight this looks much the same as the induction coil type, but its operation is fundamentally

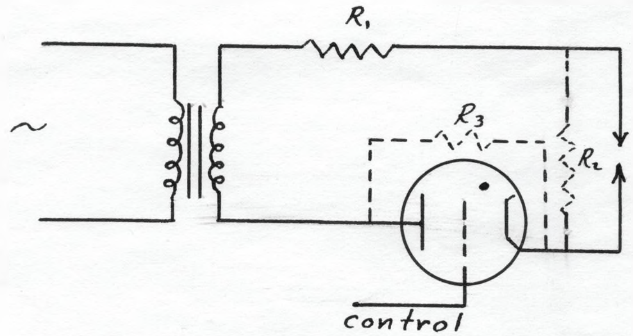

Figure 7

Thyratron punching circuit--

secondary control

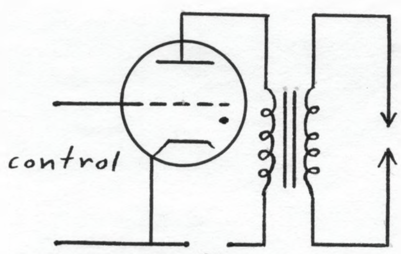

Figure 8

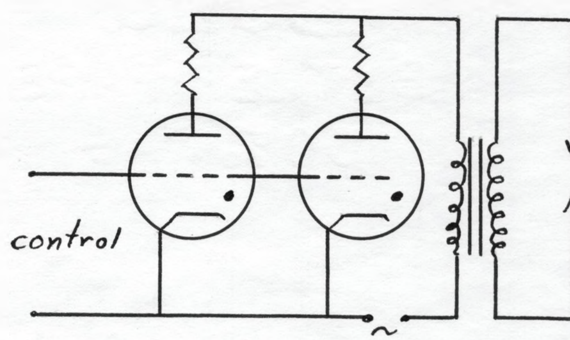

Figure 8a

Thyratron punching circuits--

primary control

different. In this the energy for punching is not stored in the core of the transformer between punches, but is drawn directly from the supply line through the tube during the punching operation.

The experimental set-up of this circuit used a pair of type 2A4G thyratrons (rated at 200 volts peak, 1.25 amperes peak) in parallel in order that sufficient current could be passed, and a 3000 volt 18 ma. neon transformer with the magnetic shunts removed to decrease the transformer impedance. This circuit was found to perform as well as any type previously tested. It was necessary to connect small individual plate resistors (about 30 ohms) in the circuit in order that one tube could not fire first and deprive the other of its firing voltage. This circuit is shown in Fig. 8a.

Both types of thyratron circuits were found to perform equally well, hence the only basis for choice between them is that of economy. It happens that no thyratrons having high-voltage low-current ratings are commercially available; thus, to use the first type of thyratron circuit, high-voltage high-current tubes must be employed. This, however, means that the tube cost will be high, since much unused capacity must be purchased. On the other hand, low-voltage high-current tubes, the kind needed for the second type of circuit, are readily available. Two type 2A4G tubes, operated in parallel, will carry adequate current, and may be purchased for less than one dollar apiece, compared with perhaps fifteen times as much for one of the other types. The one possible disadvantage of the second circuit is that a separate transformer must be used for each pair of electrodes. However, such transformers are comparatively low-priced, even when made to special order.

The second type of thyratron circuit is also considered to be preferable to the parallel igniter type, the only other practical circuit, since fewer parts are needed.

B. Reading Circuits

Only one basic type of reading circuit was investigated; this is shown in Fig. 9. Since the desired output from the reading apparatus to the computing machine is in the form of relatively low-voltage impulses, the design problem was rather simple. A 2000 volt transformer connected to the line was used as the source of voltage. In order to sharpen the reading-voltage impulses applied to the card a type FG-17 thyratron was connected in the secondary circuit and arrangements made to fire it on the peak of every positive half-cycle. The current flow in the secondary circuit was through a 25,000 ohm resistor, across which was developed the actual reading voltage. The wave-form of the reading impulses was approximately as shown in Fig. 9a. In series with the electrodes was a small condenser (0.001 mfd.), which was shunted by a small neon bulb. The discharge through a hole in the card charged the condenser; while the neon bulb prevented the condenser voltage from reaching a dangerously high value.

In operation the circuit was unreliable, for although appearance of a hole always produced a charge on the condenser, often a false reading impulse was obtained because the leakage resistance across the electrode insulation was too low. In order to eliminate this, the modification shown in Fig. 10 was devised. In this the current through the hole flowed through a resistance of about 30,000 ohms. The voltage which could be developed across this resistor due to the electrode leakage was very small, since the ratio of the load resistance to the leakage resistance was small. When a discharge passed between the electrodes, the largest part of the applied voltage appeared across the resistor, and a portion of this was applied to the condenser through the neon bulb.

This circuit functioned very reliably. Cards could be left between the electrodes indefinitely without being punctured by the reading voltage, yet upon placing a previously punched spot between the electrodes, a reading impulse was always obtained. Nothing about the circuit was critical. It is plain from a consideration of the diagram that any number of electrode pairs can be supplied by one transformer and thyratron combination, provided only that the regulation is good enough so that an excessive voltage drop does not occur when all electrodes are drawing current.

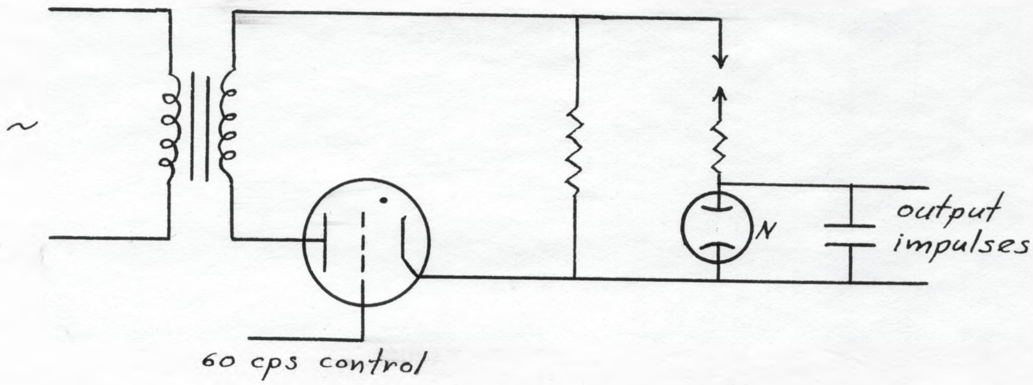

Figure 9

Reading circuit

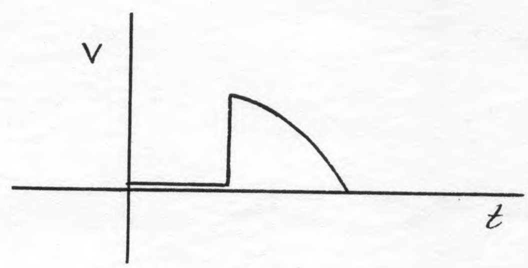

Figure 9a

Voltage impulse applied to electrodes

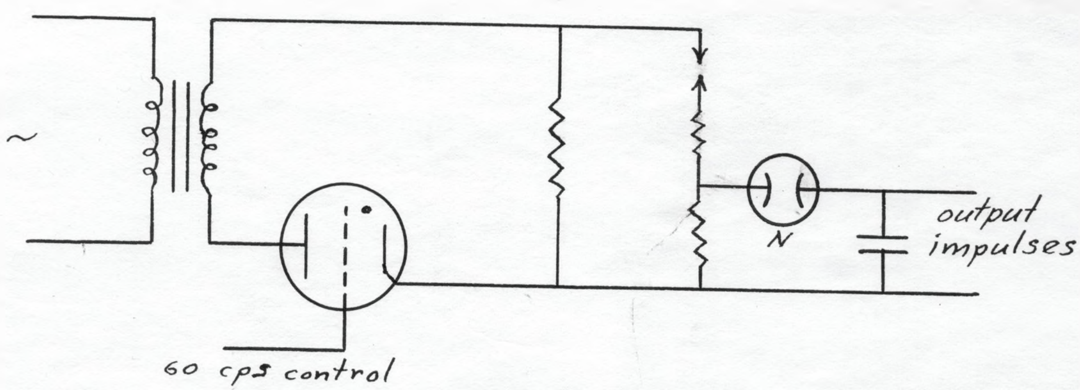

Figure 10

Improved reading circuit

IV. DETAILS OF MECHANICAL CONSTRUCTION

The design of the mechanical apparatus was quite straightforward. Two complete mechanisms have been constructed which are identical in all respects except for electrode assemblies. The size of cards handled by the devices is 5.95" by 10.1", which allows 30 rows of 50 holes each to be punched on one card, a total of 1500 altogether.

Plates I, II, and III reveal the main features of the mechanisms, except for the electrode holders, which have been removed. Plate I is a rear view, showing the platforms on which the cards are placed, the fingers for pushing the cards into the feed rollers, and the side guides for keeping the cards in the proper position. Also, the end of one bearing plate is visible, showing the spring mounting of the upper feed roller; the purpose of this spring arrangement is to provide high pressures on the card in order to insure positive drive by the roller.

Plate II is a front view showing the rollers and their driving gears. A common shaft runs through the two mechanisms, and separate gearing is employed from this shaft to each of the roller pairs. The main drive shaft rotates at one rps and the gear ratio is 3.5:1, giving a peripheral speed of 11 inches per second to the rollers, which have a diameter of one inch.

Plate III is a view of the under side showing the cam arrangement for driving the cards into the rollers. The shape of the cam is such that the card is accelerated uniformly until its edge reaches the electrodes, and thereafter moves at the constant roller velocity until it reaches the rollers.

The cam follower actuates a shaft which in turn actuates both card pushers simultaneously. This arrangement eliminates the necessity for making two identical cams. The cam follower is automatically latched up at the end of one revolution of the cam, and is released by the electro-magnet shown directly below the latch in the photograph. In operation the opening of the latch is controlled electrically by the computing machine in such a way that it opens only when the cam is in the correct angular position with respect to the machine. Thus when the operator desires to punch or read a card, he merely places it on the proper platform and pushes a button. When the correct point in the machine cycle is reached, the latch is released, and the card is fed through. The follower then latches automatically.

The sketch of Fig. 11 shows the arrangement of the electrodes and their holders. These are mounted between the rollers and the platform.

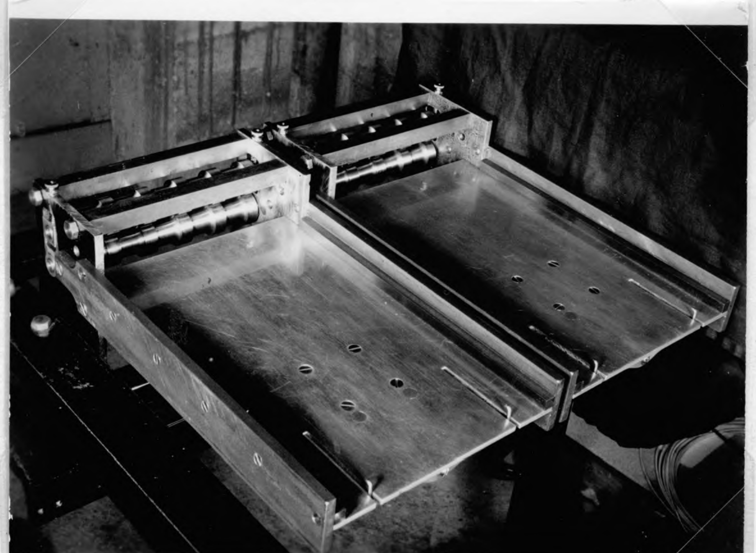

Plate I

Upper rear view of mechanisms

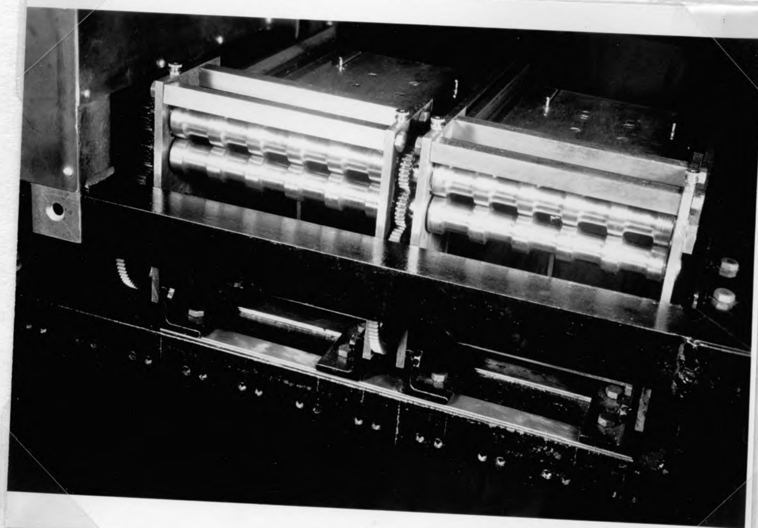

Plate II

Front view of mechanisms

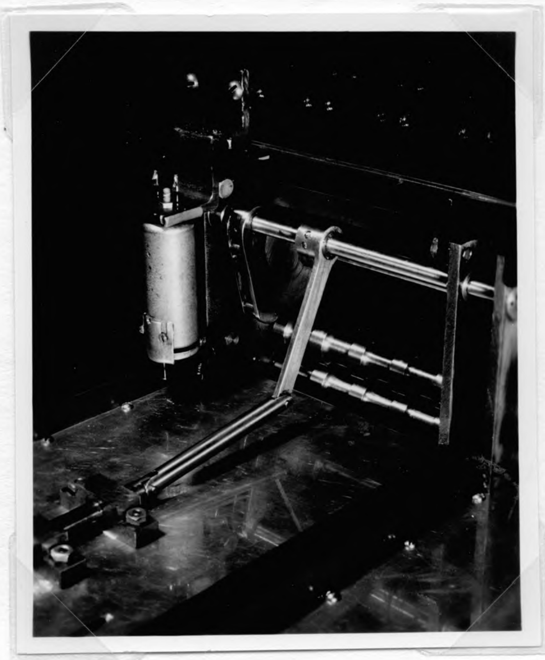

Plate III

View from below

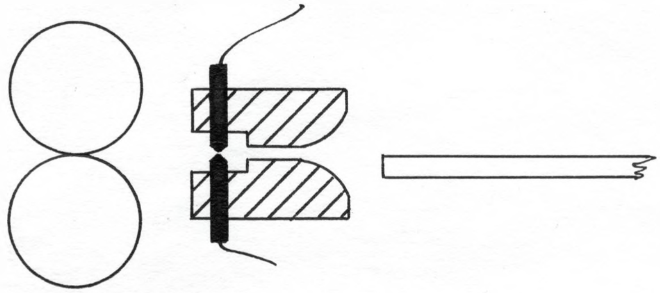

Figure 11

Electrode arrangement

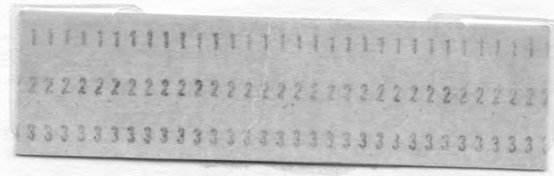

Plate IV

Section of card punched
by new method

V. CONCLUSIONS

The mechanical devices for applying the new system of card punching and reading to a computing machine have been completed. The punching and reading circuits have not been built in permanent form, but their construction will be based on the designs discussed in this paper. Plate IV shows a section of a card which has been punched by running it through the mechanism, using the primary-connected thyratron circuit for punching. The holes were punched one-sixtieth of a second apart. This particular card was put through the machine several times and shows the perfect synchronization of the feed and phasing systems with the computing machine.

Laboratory tests show the new method of card handling to be admirably suited to high operating speeds, and to satisfy all of the requirements specified at the beginning of this paper. The new method is expected to perform well in actual use.

VI. APPENDIX

Several patents relating to the new method of recording and reading data are listed and briefly discussed below.

U.S. patent 1,138,089, May 4, 1915; W. J. Crumpton.

This patent discloses a method of marking cards by means of electrical discharges, but makes no mention of reading.

U.S. patents 1,916,232, July 4, 1933 and 1,991,516, Feb. 19, 1935; Robert E. Paris.

These patents disclose a method of reading cards having small perforations by means of high-voltage discharges.

U.S. patent 2,051,390, August 18, 1936; Robert E. Paris.

This patent discloses a specially treated card for use with electrical discharge methods of card reading.

U.S. patent 2,055,016, Sept. 22, 1936; Robert E. Paris.

This patent discloses a method of simultaneously typing numbers on cards and puncturing by means of a combination of perforating points and electrical discharges. The purpose of the discharge is to make the sides of the perforated holes semi-conducting.

VII. ACKNOWLEDGMENTS

The writer wishes to express his sincere thanks to Dr. J. V. Atanasoff, who directed the research; to Mr. J. C. Pemberton, who gave many helpful suggestions; and to Mr. G. H. Weiseman, who did much of the mechanical construction.