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THE COLLEGE OF AERONAUTICS
CRANFIELD

FACTORS AFFECTING PUNCHING SPEEDS OF HOLLERITH OPERATORS - MECHANICAL FACTORS OUTSIDE THE CONTROL OF THE OPERATORS

by

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Factors affecting Punching Speeds of Hollerith Operators. Mechanical Factors outside the Control of the Operators.

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SUMMARY

One of the major influences governing punching speeds is the operator's reaction to what she regards as the innate stiffness of the punch. This Note reviews those factors which are attributable to the machine rather than the operator, and seeks to assess their relative importance from the viewpoint of their effect on punching performance.

On the basis of a number of tests using a standard keyboard under normal operating conditions and employing motion-study techniques, the following conclusions are reached respecting the influence on punching speeds of the various factors.

1. The stroke of the key has very little influence on punching speeds
2. The spacing of the keys has an appreciable effect on punching speeds
3. The so-called 'stiffness' of the punch is often not stiffness in the mechanical sense, but is a physiological reaction in the operator to different key-top pads
4. A certain amount of variability of pressure is always inherent in the machine, and operators are, within certain pressure ranges, extremely sensitive to such variability.

An Appendix to the Note describes the key-punch 'Pressure Pick-up' which was designed for the tests.

This Note is an extract from a thesis submitted by Mr. T.R. Majewski in part fulfillment of the requirements for the award of the Diploma of the College of Aeronautics.

1. INTRODUCTION

The speed of punching does not only vary with the skill and ability of the operator and the legibility of the documents, etc., but also depends on the punch itself. It is difficult to estimate to what extent the mechanical variation in the punch may contribute to slowing down the speed of punching. At present we have no standard of comparison between one punch and another, nor any positive indication of the magnitude of forces necessary for operation of the various parts of the mechanism.

There are good reasons however to believe that these mechanical factors do affect, sometimes seriously, punching performance of the operator.

We often hear operators refer to one punch machine as being 'good' and easy to punch on, and they regard another as 'stiff' and hard to operate.

In this note we will try to analyse these mechanical variations, and grade them in relation to their importance. The factors under consideration are

(a) Stroke of key
(b) Spacing of the keys on the key board
(c) Pressure exerted by the finger on the key, and general freedom of the mechanism.

2. Stroke of key

The amplitude of the excursion of the operator's finger, at normal punching speed, is, approximately, just under one and a half inches. Taking the speed of punching as constant, the amplitude will vary slightly with the stiffness of the machine and the weight and length of the moving part of the operator's arm. The amplitude of the operator's finger on verification is reduced by 25 per cent when compared with amplitude while punching, taking the speed of punching as constant.

It does not make much difference however in the punching amplitude of the operator's finger, whether the stroke is very small, say $\frac{1}{8}$ inch, or relatively large, say 1 inch, as long as the 'Stiffness' of the key will remain the same. It can be said that most of the time in punching is taken in starting, stopping and changing direction, so punching rate is relatively constant regardless of the stroke of the key.

3. Spacing of the keys on the key board

The investigation of the relationship existing between spacing of the punch keys and speed of the punching was approached from two planes:

(a) Micro-motion time study

(b) Overall time study

The former, with the help of high speed photography, and the latter by means of orthodox time study technique, using a standard stop watch.

(For latter, see Appendix A for description of tests).

3.1 Micro-motion time study (see Fig.1)

If we assume that the complete cycle consists of time elapsed from time of punching one hole to the moment of touching the top of another key, the time is distributed for an average operator as follows:

The duration of stroke	9.7 per cent	of
Stopping and changing direction	31.4 per cent	total
Reaching an adjacent key	58.9 per cent	time

The time for stopping and changing direction on an average was 0.0625 seconds for both the punch and verifier machines. However the time elapsed from taking the finger from the '9' key to touching the '0' key was 0.109 seconds for the punch and 0.094 seconds for the verifier. No apparent time difference was detected on punching the keys spaced in longitudinal direction (e.g. keys 9 and 3) from keys spaced in latitudinal direction(e.g. keys 7 and 9).

3.2 Overall Time Study

For the purpose of investigation the key board was divided into three groups.

(a) Four adjacent keys (1,2,4 and 5)
(b) Four widely spread (1,3,7 and 9)
(c) Four selected at random(from the 9 numerical keys)

The results obtained show that an 8.5 per cent increase of speed was recorded with four adjacent keys as compared with four keys selected at random. A 6.6 per cent drop in punching speed was recorded with four widely spread keys as compared with four keys selected at random.

The increase in punching speed for cards punched by the selection of four adjacent keys as compared with four keys widely spread was 15.1 per cent.

4. Pressure exerted by the finger on the key, and the general freedom of the mechanism.

In this section we shall discuss the pressure, or as it is commonly called, stiffness of the key

The problem of pressure has occupied considerable attention in the past, and caused some controversy, over the seriousness of this factor on the operation of key punching and verifying. The main difficulty lies in the inability of measuring effectively and accurately the resultant pressure gradient on pressing the key under normal operational conditions.

It was clear however that no solution could be found until a suitable instrument for measuring pressure was constructed. Such an instrument was designed during the course of the investigation, and in Appendix B of this paper may be found a description of its development.

The 'Pressure Pick-up' as it was called, had to satisfy three conditions, namely:

(a) Sensitivity to very small pressures
(b) Responsiveness to pressure pulses occurring in a short interval of time (average duration 0.015 secs.)

(c) Compactness in size and light weight (it had to be no more than $\frac{5}{8}$" high and $\frac{1}{2}$'' in diameter).

Thanks to the invaluable help of Mr Reason of Taylor, Hobson and Co. it was possible to make a pick-up which satisfied the above conditions.

The experiments were then directed to a systematic investigation of the pressures and their effects on the efficiency of the operation.

The pressure gradient on pressing the key takes the form as shown in Figs.2,3 and 4. Fig.2 shows a recording of the gradient on a Cathode Ray tube whilst Figs. 3 and 4 were recorded by means of a Rectilinear Recorder (Talysurf).

There are three distinct stages of pressure distributions:

(1) Gradual build up of pressure up to the point of penetration of a card.

(2) Rapid drop in pressure on penetration

(3) Increase of pressure due to further displacement of spring due to impact made by involuntary movement of mass of moving parts of the operator's arm.

The photograph shown in Fig. 2 and graph, Fig. 3, were taken under normal operational conditions, while graph, Fig. 4, was obtained on relatively very slow application of pressure. All other conditions were exactly the same for both cases.

Comparing the two curves of Figs. 2 and 3 with Fig. 4,there exists a difference of 40 grams in maximum pressure necessary for penetration of card and 60 grams in maximum pressure force caused by the momentum of the operator's hand.

These small differences will always be present unless we could ascertain that elastic diaphragm of the pressure pick-up will be displaced by the force applied exactly at the same place. (See Appendix C).

The pressure force applied by the operator's finger in normal operational conditions is distributed in the following manner:

1) A force of approximately 50 grams is required to operate the feeding mechanism of the punch.

2) A force of approximately 480 grams is required to perforate the card.

3) A force of 670 grams is exerted by the finger on the key of the punch after the penetration of the card.

From the above it can be seen that on an average a force of 190 grams, or 39.5 per cent more than necessary for the penetration of the card is caused by involuntary momentum (impact) of the hand produced on rapid oscillation.

To confirm this result a series of 9 tests were conducted with varying static pressure of the punch and verifier from approximately 130 grams to 570 grams.

For each of the 9 tests the operator was requested to punch at normal operational speeds.

The total force applied by the operator in punching in every case was far above its nominal value.

Fig. 5 shows the relationship between total pressure exerted by the operator while punching and nominal pressure required for the process of punching. It can also be seen that the operator is apparently not very sensitive to large changes of pressure below 350 grams of nominal pressure, while the changes of pressure in the mechanism above 500 grams produce a rapid increase in total pressure if the speed of punching remains constant. This is probably part of the answer to the query why operators are so sensitive to small manufacturing variations occurring in the freedom of general movement of the mechanism of the key punch machines.

In the region of pressures necessary for punching of cards, approximately between 460 and 560 grams, for a change of 90 grams in the mechanism, the operator is required to supply an additional 200 grams of force to keep her speed of punching the same.
The remainder of the answer lies in the fact that what operators call 'stiffness' or pressure, does not necessarily mean pressure.

To verify this statement we conducted two tests. In one, operators were required to punch a number of columns on two punches. One was usually referred to as being 'old' and easy to operate and the other'new' and 'stiff'. The pressure of the two punches recorded by the pressure pick-up was exactly the same in both cases (Figs. 6-9). The difference only existedin the rubber pads covering the tops of the keys, the former pads being well worn out and the latter comparatively new. In another test rubber pads were turned 180° (unknown to the operators) and, after punching, the machine was immediately found to be softer than usual. The reason that operators can tell that someone else has used their punch previously lies not in any mechanical alteration being imposed on it, but simply because each operator adjusts the position of the punch relative to her own arm position. Every small change in the punch position on the table will result in the operator punching slightly off her normal vertical direction, which in turn produces detectable changes in pressures.

(For graphs obtained on pressing the keys of the verifier and punch, see Figs. 10-1).

Conclusions

The nominal pressure forces existing in the key punch machines are of the order of 460 to 560 grams. However, the force exerted by the finger on the key of the punch is approximately 670 grams, i.e. 39.5 per cent more force than necessary is caused by involuntary momentum of the hand produced on rapid oscillations.

It does not make much difference in the amplitude of the operator's finger during punching whether the stroke of the key is very small or relatively large as long as 'stiffness' is constant and speed of punching sufficiently high.

APPENDIX A

Test 1

The Object of the Test

To establish the relationship existing between spacing of the punch keys and speed of punching.

Conditions of the Test

The following factors were kept constant throughout the tests in this section:

(a) Work layout

(b) Time duration and period of day

(c) The size and layout of the information on the document

(d) Temperature, light, noise

(e) Punch machine.

Procedure of the Test

The selection of the keys was obtained in the following way. The key board was divided into three groups:

(a) Four adjacent keys (1, 2, 4 and 5)

(b) Four widely spaced (1, 3, 7 and 9)

(c) Four selected at random (from existing 9 keys).

For each of the groups, a large number of cards was typed and the choice of groups (combinations of any of the four keys) was obtained at random.

The time duration chosen was 15 minutes and for each group experiments were repeated three times (total number of tests was nine), at the same time of the day with a view to obtaining better average results.

Results

The average number of cards punched in a constant time of fifteen minutes was:

For Group I (adjacent four keys)	=	115
For Group II(widely separated)	=	99
For Group III (random selection of four keys from nine)	=	106

The results obtained show that an 8.5 per cent increase of speed was recorded with four adjacent keys as compared with four keys selected at random. A 6.6 per cent drop in punching speed was recorded with four widely spaced keys with respect to four keys selected at random.

The percentage of error checked on the verifier was found to be almost constant for each of the groups, and hence was neglected.

APPENDIX B

Development of Key-punch Pressure Pick-up

The inability to measure the resultant pressure gradient on pressing the key effectively and accurately, under normal operational conditions, with orthodox pressure measuring devices, necessitated the construction of a complex pickup in order to obtain the necessary degree of accuracy and sensitivity.

The device to be constructed had to satisfy three conditions:

(a) Sensitive to very small pressures;

(b) Responsive to pressure pulses occurring at short intervals of time (average duration 0.015 secs.)

(c) Compact in size and light in weight (no more than $\frac{5}{8}$'' high and $\frac{1}{2}$'' diameter).

It was clear that if the above conditions were to be successfully fulfilled the investigation must be directed into a development of electronic devices, as any mechanical, hydraulic or other device operated on similar mechanical principles would not be responsive enough, nor would it satisfy conditions of size.

Development of Project I - Strain Gauge Measuring Device

The first attempt was made with the construction of a steel ring made from a watch spring, $\frac{3}{4}$'' in diameter on the sides of which two small size strain gauges were placed. On the top of the ring a rubber tab was fixed similarly to those situated on the top of the keys of the punch (see Fig.13).

On pressing the top of the steel ring deflected within its elastic limit stretching the electric gauges, this caused a change of resistance which in turn was indicated by a proportional change in current on sensitive galvanometer. For convenience the galvanometer was calibrated in terms of grams.

Limitations of the Method

It was found that this method had three main disadvantages:

(a) The necessity of having 4 wire connections and the size of the strain gauges resulted in a very unsatisfactory arrangement. The whole device had to be approximately 1 inch above the level of the key board.

(b) The strain gauges were not responsive enough to pressure cycles occurring in a short interval of time.

(c) The measurements of the pressure were only possible with application of a cathode ray tube as the inertia of the needle in the galvanometer made all results unreliable.

The above conditions implied that any future investigation of the pressure could not be possible, under normal operational conditions, even if results obtained were to some extent satisfactory.

The project of the strain gauge pressure measuring device was therefore abandoned.

Project II

The inability of measuring pressures successfully with the application of strain gauges brought about the development of the pressure pick-up operating on either a capacity or an inductance principle.

The final choice was governed by the already existing equipment in the College, operating on broadly similar principles to those conceived for the pressure pick up.

The Taylor and Hobson Talysurf instrument is a surface finish measuring device. The surface irregularities are measured by means of a stylus which is traversed across the surface by means of a motorised driving unit. The up and down movements of the stylus control a variable inductance, by means of which the movements of the stylus are converted into corresponding charges of electric current, which is amplified by means of a valve amplifier and then used to control:

(a) A Rectilinear Graph Recorder providing a representation of the profile of a cross-section of the surface irregularities

(b) A scale-and-pointer instrument.

Development

Applying this principle, a small unit was made (see Fig.14) consisting of a cylindrical container threaded on the inside, and closed from the top by a fine aluminium alloy diaphragm 0.018'' thick, and attached to the centre a small soft iron core. The diaphragm was then calibrated in the range of pressures necessary for the punching operation. Inside the aluminium container a special inductive coil was fitted by Mr Reason of Taylor and Hobson. In this way the first stage was achieved. Instead of the stylus moving up and down a deflection of the diaphragm on striking the top produced changes in inductance and later corresponding changes in the electric current.

The next step was to develop a new control unit which normally houses a number of elements intimately associated with the pick-up as the existing control unit unsatisfactory due to rapidity of oscillations imposed on it and mode of operation.

The control unit as well as a special unit enabling transmission of changes of current on to the cathode ray tube was again developed by Mr Reason.

Preliminary Tests

The objects of preliminary tests were to calibrate responses of the Cathode Ray Tube and Rectilinear Graph Recorder in terms of pressures, and to establish the degree of accuracy obtainable in measuring pressure pulses on the Rectilinear Recorder.

The calibration charts of the apparatus were obtained by applying static loads from 0-1,000 grams.(see Figs 15 and 16) and measuring corresponding changes in voltage displacement on the Cathode Ray Tube and on the Rectilinear Recorder.

The tests for validity of results obtainable for the Recorder were carried out in the following way:

The pressures on pressing the key were recorded instantaneously on both the C.R. Tube and Rectilinear Recorder at various speeds, varying from normal operational speeds to very slow movements.

The variation of pressures as obtained on the C.R. Tube and Rectilinear Recorder were found to be negligible and all latter tests were made using the Rectilinear Recorder. For pictorial views of the arrangement of work and apparatus see Fig.1 .

Limitations

(a) In the present stage development it was impossible to construct a pick up of lesser dimensions. The unit is approximately 0.47'' above the level of the Key Board.

(b) It is necessary to take a number of readings for each result required and select one with a maximum displacement. .ince the diaphragm has its maximum sensibility in the centre and every displacement caused by a force applied not in the centre, will not correspond to the correct pressure.(see also Appendix C)

APPENDIX C

Pressure Pick-up Diaphragm Tests

Object of Test

To find out the thickness of diaphragm plate of constant diameter deflecting 1/1000 inch under an approximate load of 2 lb.

Procedure

The fixture as shown in Fig.1 was made in the workshop. During the test it was firmly held between the jaws of the vice.

(1) The direct load was applied through the medium of flat steel plate on the walls of the cylinder. No deflection was observed under 12 lb load.

(2) Load required to overcome stiffness of the gauge. Under the load of $5\frac{1}{2}$ oz. the stylus of the gauge moved 0.002" which was considered sensitive enough for the purpose of the experiment.

(3) Total load required to produce 0.001" deflection plus load needed to overcome stiffness of gauge.

The 34 oz. produced deflection of 0.001" of the gauge. Therefore the net load required to produce 0.001" was found to be 28.5 oz.

The thickness of the diaphragm giving this deflection was found to be 0.018".

The load was applied through 0.318" diameter non-metallic washer of 0.022" thickness.

Load	Deflection
16 oz	no def.
17	no def.
18	no def
19	.0002"
20	.00025"
21	.0003"
23	.0004"
24	.0005"
25	.00065"
26	.00065"
28	.00065"
29	.0007"
31	.00085"
33	.00095"
34	.001"

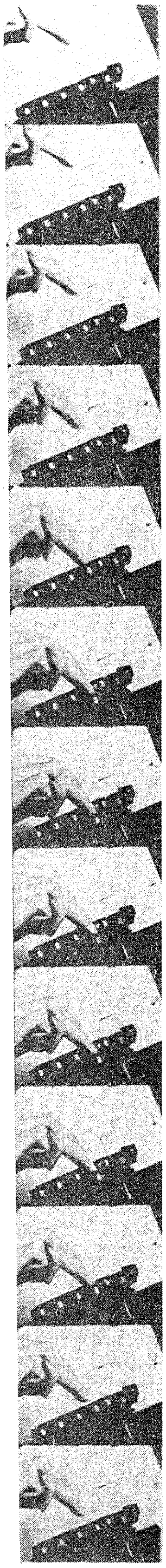

FIG. 1

PUNCHING OPERATION

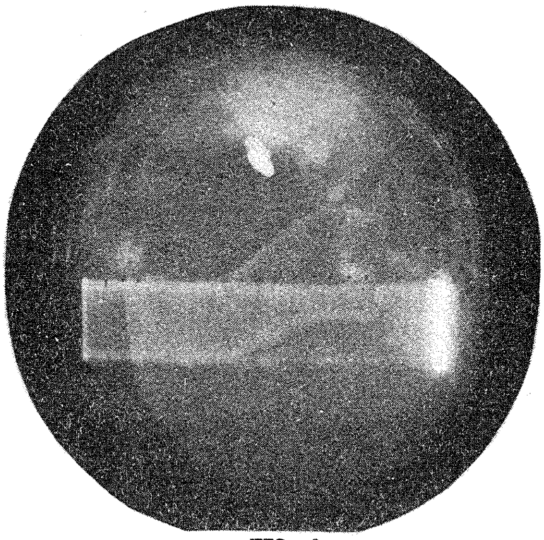

FIG. 2

NORMAL APPLICATION OF PRESSURE

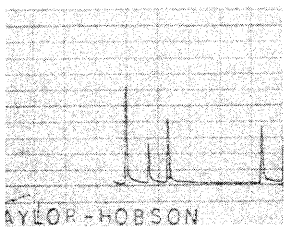

FIG. 3

NORMAL APPLICATION OF PRESSURE

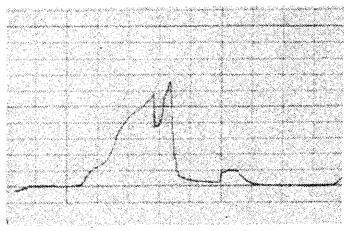

FIG. 4

SLOW APPLICATION OF PRESSURE

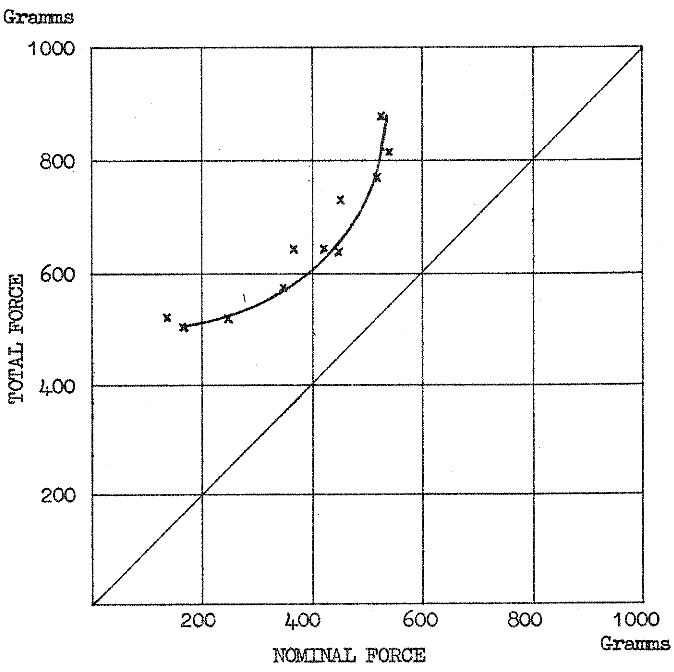

FIG. 5

RELATIONSHIP BETWEEN TOTAL PRESSURE EXERTED BY THE OPERATOR WHILE PUNCHING AND NOMINAL PRESSURE REQUIRED FOR THE PROCESS OF PUNCHING.

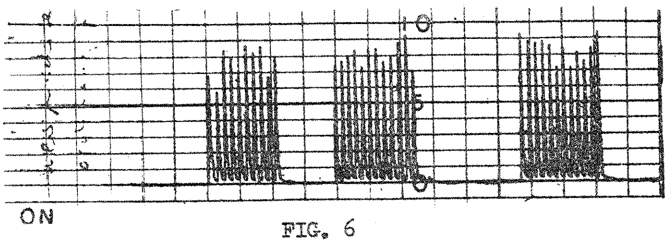

FIG. 6

NEW AND STIFF PUNCH

Average pressure force recorded
approx. 580 grams.

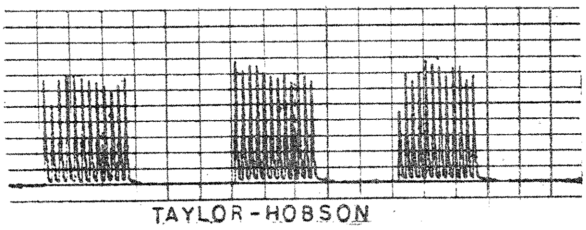

FIG. 7

PUNCHING WITHOUT THE CARD IN MACHINE

Pressure force recorded 520 grams

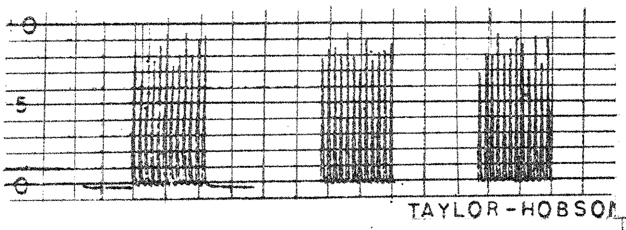

FIG. 8

OLD PUNCH

Average pressure force recorded
580 grams

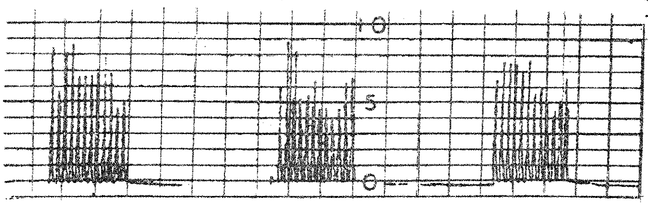

FIG. 9

PUNCHING WITHOUT THE CARD IN MACHINE

Pressure force recorded 520 grams

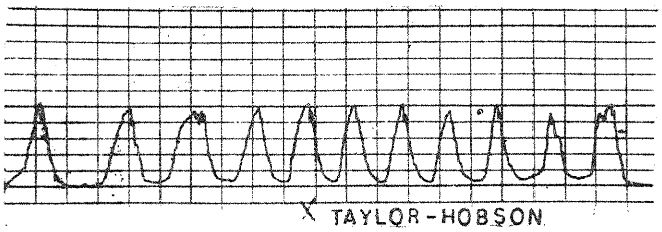

FIG. 10

ANALYSIS OF WAVEFORMS AT SLOW PUNCHING

Peak pressure = 385 grams
Drop due to penetration = 310 grams
Increase due to momentum of hand = 360 grams

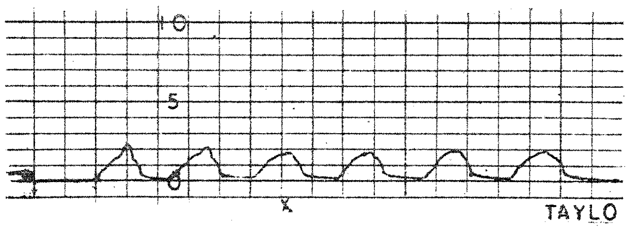

FIG. 11

DISTRIBUTION OF PRESSURE IN DISPLACING THE
KEY WITHOUT THE CARD IN THE MACHINE

Maximum pressure = 130 grams

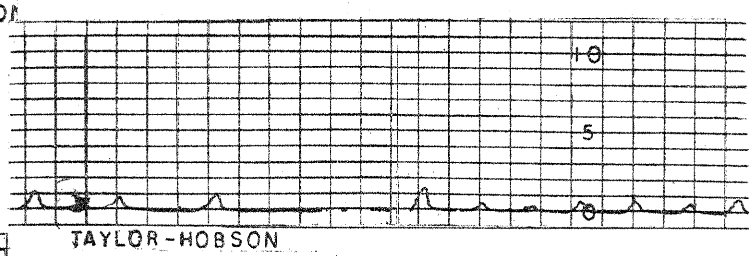

FIG. 12

PRESSURE REQUIRED TO OPERATE MECHANISM

Maximum pressure = 50 grams

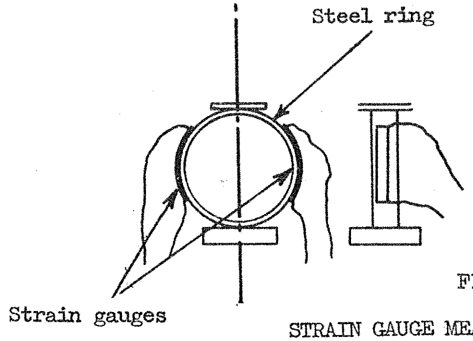

FIG. 13

STRAIN GAUGE MEASURING DEVICE

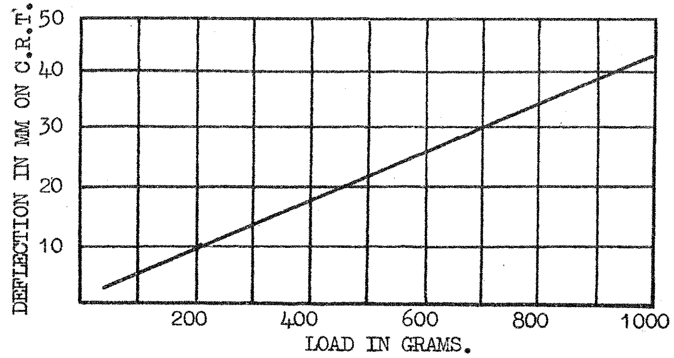

FIG. 15

CALIBRATION CHART OF CATHODE-RAY TUBE

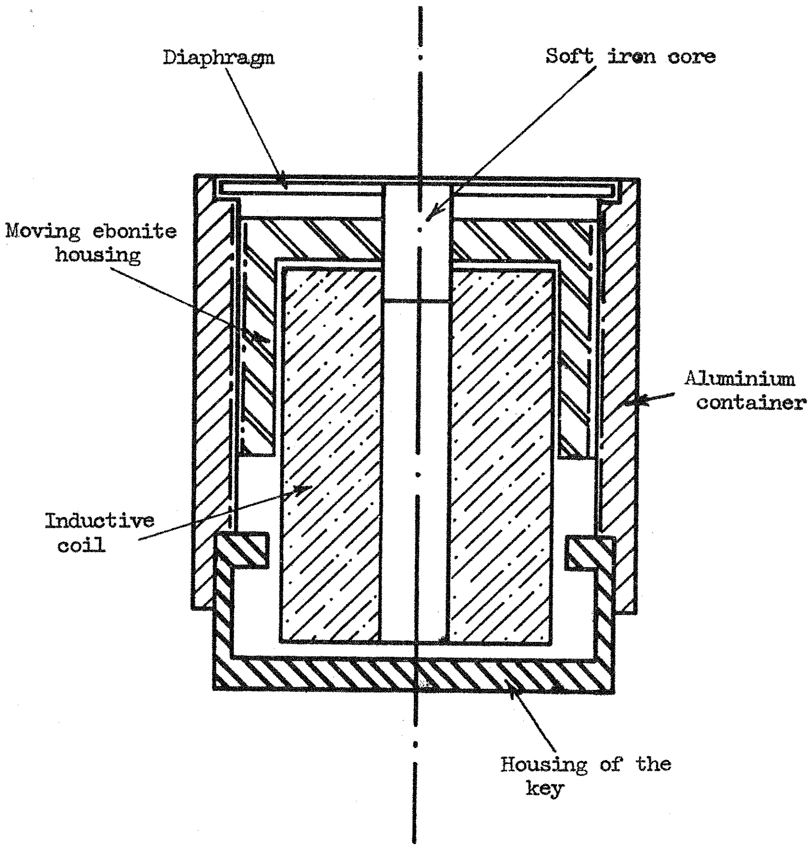

FIG. 14

PRESSURE PICK-UP

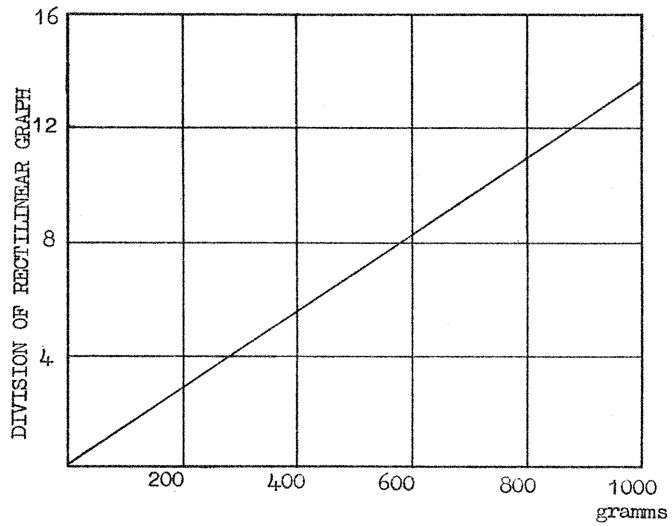

FIG. 16

CALIBRATION CHART OF RECTILINEAR GRAPH RECORDER

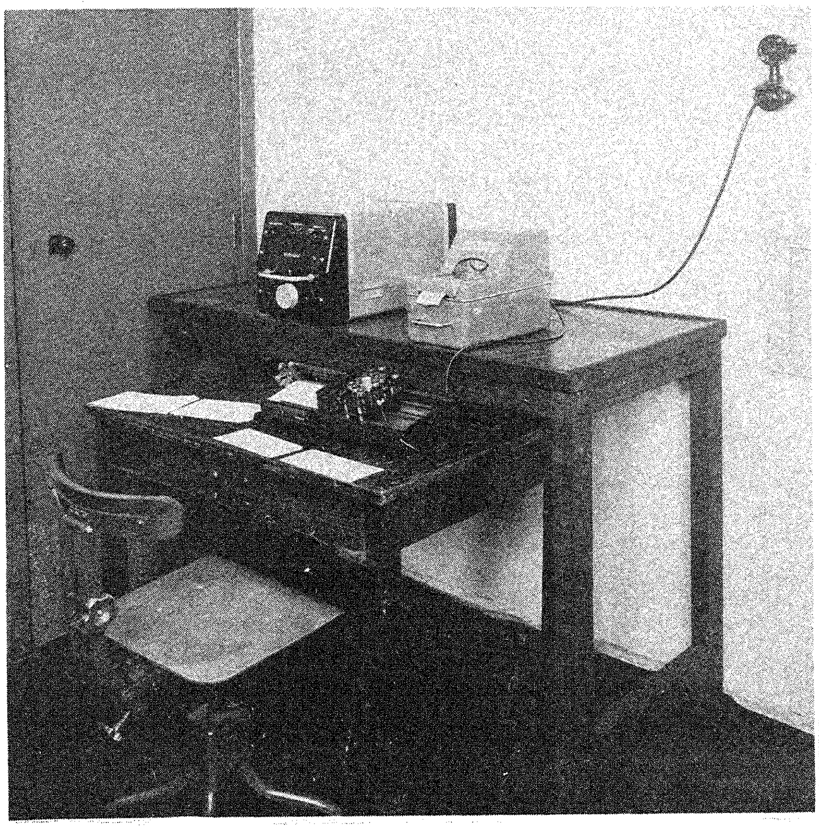

FIG. 17

ARRANGEMENT OF WORK AND APPARATUS

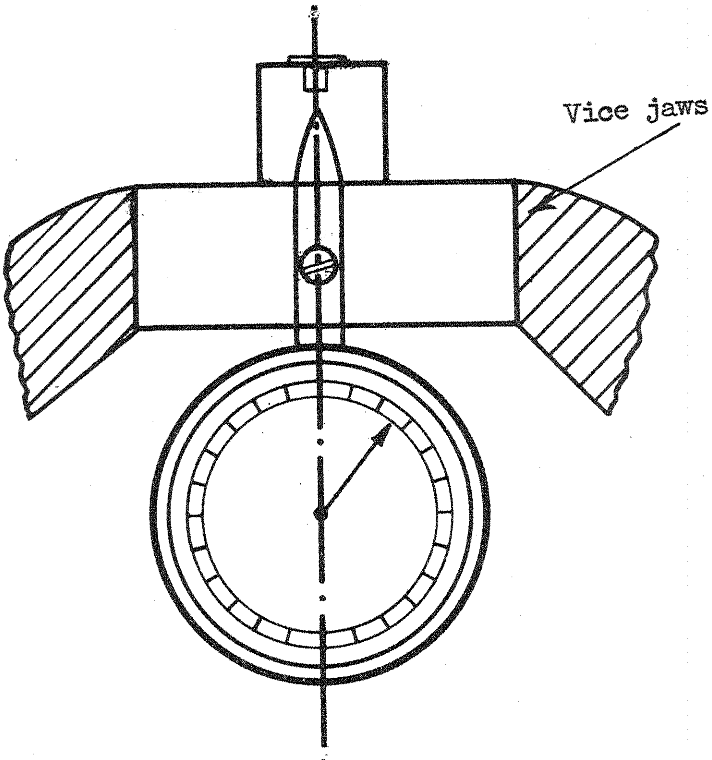

FIG. 18

PRESSURE PICK-UP GAUGE