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STUDIES OF HAND MOTIONS AND RHYTHM APPEARING IN FACTORY WORK

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STUDIES OF HAND MOTIONS AND RHYTHM APPEARING IN FACTORY WORK

Introduction

Introduction.—Wherever manual work is performed there is always the problem of finding the easiest and most economical way of doing the task. Because a large percentage of factory work and office work is manual much thought has been given to the improvement of labor effectiveness in industry.

Since all "manual work" is done by means of the hand or other parts of the body, the study of body movements has been found to be a valuable approach to the problem of finding better and less fatiguing ways of doing work.

This study of the movements of the members of the body with the purpose of eliminating all unnecessary motions and building up a sequence of the most useful motions is known as *motion study*.

Not only is it highly desirable for the worker himself to know how to work effectively, but it is equally important that those who design the equipment, lay out the work, and supervise the operations, have a knowledge of the principles of motion economy.

Although much information is available that may be used in working out effective methods of doing work, there is still a pressing need for further knowledge in this field.

This bulletin, the second[1] in a series, presents the results of studies made to discover fundamental data that are common to all kinds or classes of manual work.

From the analysis of the movements of the various members of the human body performing many different kinds of work it has been found that all motions may be divided into eighteen different well defined classes. These eighteen fundamental motions or therbligs[2] are widely known and will be used in this bulletin. A

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1 The first bulletin in this series was "An Investigation of Some Hand Motions Used in Factory Work," by Ralph M. Barnes, 63 pages, 1936, Bulletin No. 6, University of Iowa Studies in Engineering.

2 Therblig is a word coined by Frank B. Gilbreth to designate the subdivisions or events that he thought common to all kinds of work. Although the eighteen therbligs are not all pure or fundamental elements in the sense that they cannot be further subdivided, they are the best classification of hand motions that we have. Moreover, they are well known and widely used in industry.

brief explanation of some of them will be given here by referring to the simple operation of picking up a fountain pen, writing and returning it to its holder.[3]

The method is shown, step by step, in the first column of the table below while the fundamental motions or therbligs are given in the second column.

FUNDAMENTAL MOTIONS OR THERBLIGS USED IN WRITING

Steps Used in Writing	Name of Fundamental Motions or Therbligs
1. Reaches for pen	1. Transport empty
2. Grasps pen	2. Grasp
3. Carries pen to paper	3. Transport loaded
4. Positions pen for writing	4. Position
5. Writes	5. Use
6. Returns pen to holder	6. Transport loaded
7. Inserts pen in holder	7. Pre-position
8. Lets go of pen	8. Release
9. Moves hand to paper	9. Transport empty

The eighteen fundamental motions, a few of which have just been described, form a basis for studying manual work of all kinds. The names and symbols of the therbligs are given in Fig. 1.

Although the data were taken with the most meticulous care, and with all the accuracy obtainable with the measuring devices that were used, the point must be noted that certain inevitable variations were introduced as a result of the fact that the movements being measured were those of human, as distinct from purely mechanical, subjects.

As general conclusions could safely be based only on investigations of a much broader scope than those reported in this bulletin no such general statements are presented.

These studies may, therefore, be considered as indicatory in nature, and the conclusions at the end of each of the several investigations are based merely on the results of that particular investigation.

The investigations reported in this bulletin were made in the Motion and Time Study Laboratory[4] at the University of Iowa.

[3] This refers to the usual form of fountain pen desk set.

[4] For a description of the laboratory see: "The New Emphasis in Time and Motion Study" by Ralph M. Barnes, *Journal of Engineering Education*, Vol. 16, No. 3, p. 239–248, Nov. 1935.

Name of Symbol	Therblig Symbol		Explanation-suggested by	Color	Color Symbol	Dixon Pencil Number	Eagle Pencil Number
Search	Sh.		Eye turned as if searching	Black		331	747
Find	F.		Eye straight as if fixed on object	Gray		399	747½
Select	St.	→	Reaching for object	Gray, light		399	734½
Grasp	G.	∩	Hand open for grasping object	Lake red		369	745
Transport loaded	T.L.		A hand with something in it	Green		375	733
Position	P.	9	Object being placed by hand	Blue		376	741
Assemble	A.	#	Several things put together	Violet, heavy		377	742
Use	U.	U	Word "Use"	Purple		396	742½
Disassemble	D.A.	††	One part of an assembly removed	Violet, light		377	742
Inspect	I.	0	Magnifying lens	Burnt ochre		398	745½
Pre-position	P.P.	8	A nine-pin which is set up in a bowling alley	Sky-blue		394	740½
Release load	R.L.		Dropping content out of hand	Carmine red		370	744
Transport empty	T.E.		Empty hand	Olive green		391	739½
Rest for over-coming fatigue	R.		Man seated as if resting	Orange		372	737
Unavoidable delay	U.D.		Man bumping his nose, unintentionally	Yellow ochre		373	736
Avoidable delay	A.D.		Man lying down on job voluntarily	Lemon yellow		374	735
Plan	Pn.		Man with his fingers at his brow thinking	Brown		378	746
Hold	H.	Ω	Magnet holding iron bar	Gold ochre		388	736½

FIG. 1. Standard symbols for therbligs.*

*Fig. 1 reprinted by permission from "Motion and Time Study" by Ralph M. Barnes, published by John Wiley & Sons, Inc.

PART I

A STUDY OF HAND MOTIONS USING THE PRINCIPLE OF THE KYMOGRAPH

INVESTIGATION NO. 1: A STUDY OF THE EFFECT OF VARYING THE EFFORT EXERTED IN MAKING SIMPLE HAND MOTIONS

Object.—The object of this investigation was to determine how the varying of effort, exerted by the operator, affected the time and distance for acceleration, movement at constant velocity, retardation, and the time for change direction, with a ten-inch movement on a slide between mechanical stops.

Equipment Used in Making the Studies.—This study and the following one (Investigation No. 2) were made with a special kymograph as the measuring and recording device. Since the principle of operation, and the procedure in using the kymograph were fully described in Bulletin 6, this will not be repeated here.[5]

Procedure.—The operator was seated directly in front of the kymograph and moved the carriage[6] B (Fig. 2) back and forth on the slide A between pins set in the slide. The movement was ten inches in length and a pencil attached to the carriage B made a vertical line ten inches long on the paper F when the kymograph was not running.

After the prescribed practice period the kymograph motor was started and the newspaper stock was drawn through between the rollers I and J at a uniform velocity of 31.9 inches per second. Thus, the pencil point drew a curve on the moving sheet of paper and an analysis of this curve gave the time, in thousandths of a second, required to make each back and forth motion. The curve also made it possible to determine the time required for the component parts of a single motion, i. e., to accelerate the hand, move at uniform velocity, retard or decelerate, and change direction.

In a preceding study[7] 28 different operators moved the slide back and forth between pins at a speed that they thought they could maintain all day.

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5 Iowa Studies in Engineering, Bull. No. 6, p. 37–51.

6 The carriage used in this study was not the same one used in the investigation reported in Bull. 6. The new carriage was lighter in weight and freer and smoother in its action than the original carriage.

7 See Bull. No. 6.

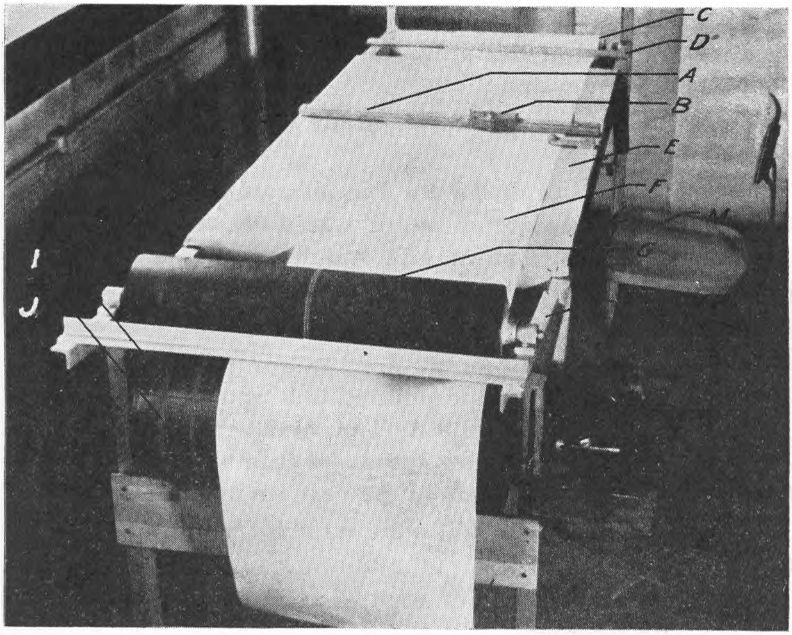


FIG. 2. Apparatus for timing and recording movements of the hand. A—oak slide; B—pencil carriage; C—supply roll of news-print paper; D—guide for paper; E—table top; F—paper; G—idle roller; H—hinged angle iron frame carrying idle roller; I—drive roller; J—heavy rubber bands glued to drive roller; M—adjustable chair for subject.

The following studies were made in order to obtain data showing the effect of variations in the speed or effort exerted by the operator in making similar hand motions. A change in the number of cycles per minute was considered as a change in effort.

In part A of the investigation the pace was set by a metronome at 80, 120, and 160 strokes per minute. A stroke was defined as a movement of the carriage either away from or toward the operator. The operators were instructed to keep pace with the metronome.

In part B the subjects were instructed to work (1) slowly, then (2) at a moderate pace, and finally (3) at their maximum speed.

Four different operators were observed in each part of the experiment.

In part A the operator practiced 40 cycles at a speed of 80 strokes per minute and then without stopping, the kymograph record was made of the next ten cycles.

The metronome was adjusted to 120 strokes per minute and the operator practiced at this speed for 40 cycles and a record was then made of ten cycles.

In a like manner the record was made at a speed of 160 strokes per minute.

Then the operator rested for five minutes and a second run, with the same procedure as before, was made at a speed of 160 strokes per minute, then at 120, and finally at 80 strokes per minute.

Five consecutive cycles from each of the six runs were analyzed and the data tabulated.

Part B of the study was conducted in a manner similar to part A which has just been described. The operator practiced 40 cycles at what he considered a slow speed and then without stopping, a kymograph record was made of the next ten cycles.

In a similar manner records were made for moderate speed and then for maximum speed.

Five consecutive cycles of each of these runs were analyzed and the data recorded.

Results.—Table I shows the average data for the operators. The time as well as the per cent of the total cycle time is given for each of the four parts of the movement, i. e., acceleration, movement at uniform velocity, retardation, and change direction. The table also gives the distance in inches and the per cent of the total distance (ten inches) covered during acceleration, constant velocity, and retardation.

Conclusions.

1. The per cent of cycle *time* used for acceleration, movement at constant velocity, retardation, and change direction tended to be constant (i. e., independent of the amount of effort exerted by the operator) in that variations were random rather than falling into any particular pattern.

2. The per cent of the cycle *distance* covered during acceleration, movement at constant velocity, and retardation tended to be constant (i. e., independent of the amount of effort exerted by the operator) in that variations were random rather than falling into any particular pattern.

TABLE I

RESULT SHEET

These data are the average results of the eight operators studied.

	TIME in thousandths of a sec.					DISTANCE in inches				VELOCITY inches/sec.		RATIO	T_a, T_p, T_d, T_o in per cent of total time				S_a, S_p, S_d in per cent of total distance		
Index of Effort	T_a	T_p	T_d	T_o	T	S_a	S_p	S_d	S	V_p	V	V_p/V	T_a/T	T_p/T	T_d/T	T_o/T	S_a/S	S_p/S	S_d/S
MOVEMENT AWAY FROM OPERATOR																			
80	306	162	116	189	773	4.24	3.84	1.92	10	23.7	12.9	1.84	39.6	21.0	15.0	24.4	42.4	38.4	19.2
Slow	252	213	149	134	748	3.29	4.28	2.43	10	20.1	13.4	1.50	33.7	28.5	19.9	17.9	32.9	42.8	24.3
120	189	117	92	111	509	3.79	3.97	2.24	10	33.9	19.6	1.73	37.2	23.0	18.1	21.8	37.9	39.7	22.4
Moderate	171	110	65	73	419	3.64	4.47	1.89	10	40.6	23.8	1.71	40.8	26.2	15.5	17.5	36.4	44.7	18.9
160	142	87	68	79	376	4.05	3.85	2.10	10	44.3	26.6	1.67	37.8	23.1	18.1	21.0	40.5	38.5	21.0
Maximum	79	63	31	40	213	3.47	4.87	1.66	10	77.3	46.9	1.65	37.1	29.6	14.5	18.8	34.7	48.7	16.6
MOVEMENT TOWARD OPERATOR																			
80	299	150	107	179	735	4.10	3.79	2.11	10	25.3	13.6	1.86	40.7	20.4	14.6	24.3	41.0	37.9	21.1
Slow	237	227	149	141	754	2.95	4.68	2.37	10	20.6	13.3	1.55	31.4	30.1	19.8	18.7	29.5	46.8	23.7
120	183	126	87	114	510	3.57	4.20	2.23	10	33.3	19.6	1.70	35.8	24.7	17.1	22.4	35.7	42.0	22.3
Moderate	142	127	76	72	417	3.02	4.84	2.14	10	38.1	23.9	1.59	34.1	30.4	18.2	17.3	30.2	48.4	21.4
160	127	97	67	83	374	3.43	4.27	2.30	10	44.0	26.7	1.65	34.0	25.9	17.9	22.2	34.3	42.7	23.0
Maximum	62	78	28	37	205	2.57	5.96	1.47	10	71.5	48.7	1.46	30.2	38.0	13.7	18.1	25.7	59.6	14.7

Subscript a denotes period of acceleration
Subscript d denotes period of deceleration
Subscript p denotes period of constant velocity
Subscript o denotes period of changing direction
No subscript denotes total element for one-half cycle
Numbers under index of effort indicate metronome rate, i. e., cycles per minute; words are those suggested to operator for subjective pace setting.

Investigation No. 2: A Study of Motion Paths Involving Different Degrees of "Change Direction"

Object.—The object of this investigation was to determine the effects of varying degrees of change direction from an abrupt change (90°) to a smooth curved change (circular movement with 5 inch radius).

The results of a previous study[8] showed that where the hand moved back and forth between fixed points, as much as 24 per cent of the total time for a cycle was required for change direction, i. e., for the hand to stop and start back in the reverse direction. This was such a large value that it seemed desirable to make a further study of changes in direction that were less abrupt than a complete reversal.

Equipment Used in Making the Studies.—The kymograph shown in Fig. 2 was used for timing and recording the movements of the hand.

Paths as shown in Table II were carefully cut from fiber board and the board was mounted above the kymograph table as shown in Fig. 3. A special pencil was made with a wide flange which rested on the upper surface of the fiber board when being used. Thus, the operator could easily keep the pencil in a vertical position while moving it around the opening.

The openings in the fiber board were of such a size that the motion paths made by the pencil on the paper were of the proper dimensions, i. e., a 10 inch square for path 1, etc.

The bottom edge (line AD in Table II) of the path was placed at an angle of 26½ degrees with the line of motion of the paper so that movements AD and BC (See figure in Table II) would not be a straight line parallel to the movement of the paper in the kymograph.

The operator, however, was in each case seated at a corresponding angle with the front edge of the kymograph table so that he faced the motion path squarely, i. e., so that AD (in Table II) was parallel to the front of his body.

Procedure.—In this study the following four motion paths were investigated (see figures in Tables II and III): Path 1—a square with 10 inch sides; path 2, a 10 inch square with the two upper corners rounded—2½ inch radius; path 3, a 10 inch square with

8 See Bull. No. 6, p. 48.

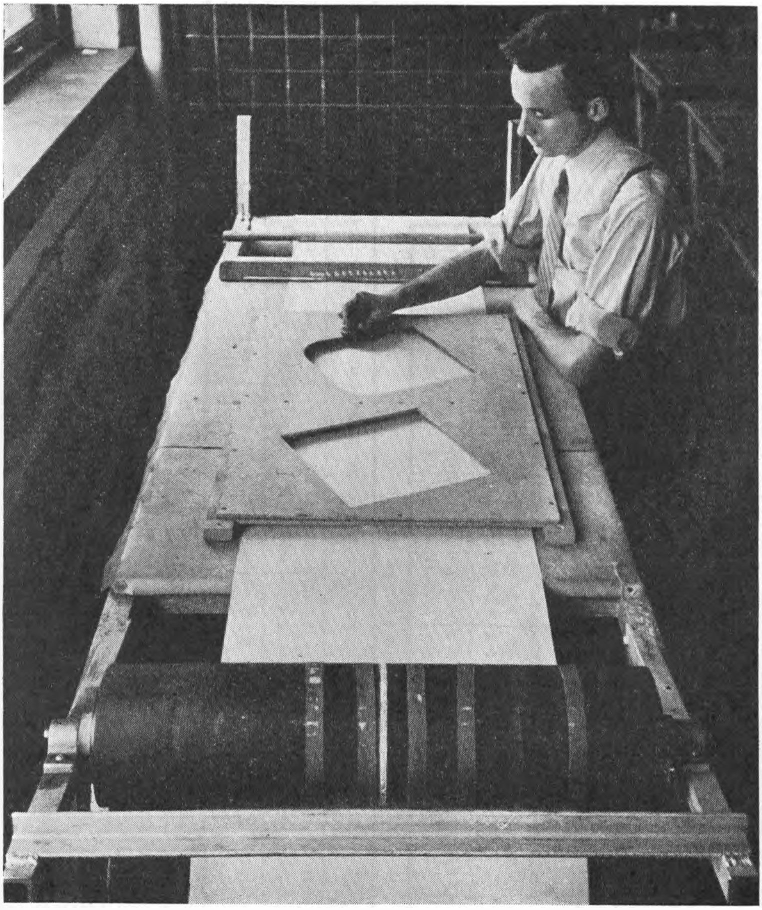


FIG. 3. Kymograph showing the location of the paths cut in the fiber board.

the two upper corners cut off at a 45° angle to give one half of an octagon, i. e., inside angles of 135°; and path 4, a 10 inch square with the upper half in the form of a semi-circle of 5 inch radius.

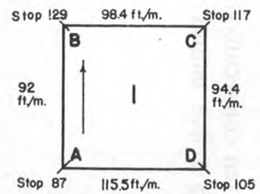
In the second part of the study the paths were inverted as shown in the figure in Table III.

The operator was seated in front of the kymograph and was instructed to move the pencil around path 1 at a speed which he thought he could maintain all day.

After a practice period of 50 cycles a record of ten consecutive cycles was made with the kymograph. Following a five minute

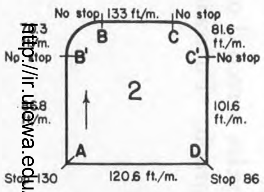
TABLE II RESULT SHEET

Velocities in feet per Minute — Time for Stops in Thousandths of a Second



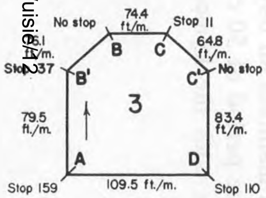
PATH No. 1 Total length of path, Distance = 40 inches, Time = 2.4536 sec., Av. Velocity = 81.5 ft./min.

	A ---------- B					B ---------- C					C ---------- D					D ---------- A				
	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total
Time in Thousandths of a Second	245	165	134	129	673	223	173	113	117	626	200	229	101	105	635	136	227	70	87	517
% Time	36.4	24.5	19.9	19.2	100	35.6	27.6	18.1	18.7	100	31.5	36.1	15.9	16.5	100	26.2	43.6	13.5	16.7	100
Distance in Inches	3.10	4.34	2.56	--	10	3.03	4.92	2.05	--	10	2.43	5.80	1.77	--	10	2.13	6.36	1.51	--	10
% Distance	31.0	43.4	25.6	--	100	30.3	49.2	20.5	--	100	24.3	58.0	17.7	--	100	21.3	63.6	15.1	--	100



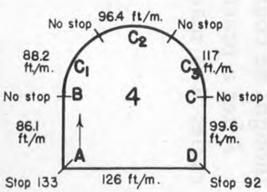
PATH No. 2 Distance = 37.89 inches, Time = 2.1398 sec., Av. Velocity = 88.6 ft./min.

	A ---------- B'					B'-B	B ---------- C					C-C'	C' ---------- D					D ---------- A				
	a	p	d	o	Total	Total	a	p	d	o	Total	Total	a	p	d	o	Total	a	p	d	o	Total
Time in Thousandths of a Second	201	188	43	0	432	279	87	82	21	0	190	240	123	147	99	86	455	147	149	118	130	544
% Time	46.5	43.5	10.0	0	100	100	45.8	43.1	11.1	0	100	100	27.0	32.3	21.8	18.9	100	27.0	27.4	21.7	23.9	100
Distance in Inches	2.47	4.17	.86	-	7.5	3.92	1.84	2.53	.68	-	5.05	3.92	2.21	3.51	1.79	--	7.5	2.13	4.85	3.03	--	10
% Distance	32.9	55.6	11.5	-	100	100	36.4	50.1	13.5	-	100	100	29.5	46.7	23.8	--	100	21.3	48.5	30.3	--	100



PATH No. 3 Distance = 38.05 inches, Time = 2.6016 sec., Av. Velocity = 73.1 ft./min.

	A ---------- B'					B' ---------- B					B ---------- C					C ---------- C'					C' ---------- D					D ---------- A				
	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total
Time in Thousandths of a Second	191	161	119	37	508	123	106	6	0	289	157	115	4	11	287	134	160	38	0	332	189	135	120	110	554	199	195	78	159	631
% Time	37.6	31.7	23.4	7.3	100	42.5	36.7	20.8	0	100	54.8	40	1.4	3.8	100	40.4	48.2	11.4	0	100	34.1	24.4	21.7	19.8	100	31.5	30.9	12.4	25.2	100
Distance in Inches	2.46	3.27	1.77	--	7.5	1.31	2.17	.92	-	4.4	1.73	2.32	.05	--	4.1	.92	2.24	1.14	-	4.3	2.85	3.02	1.52	--	7.4	2.95	5.81	1.59	--	10.35
% Distance	32.8	43.6	23.6	--	100	29.8	49.3	20.9	-	100	42.2	56.6	1.2	--	100	21.4	52.1	26.5	-	100	38.5	40.9	20.6	--	100	28.5	56.1	15.4	--	100



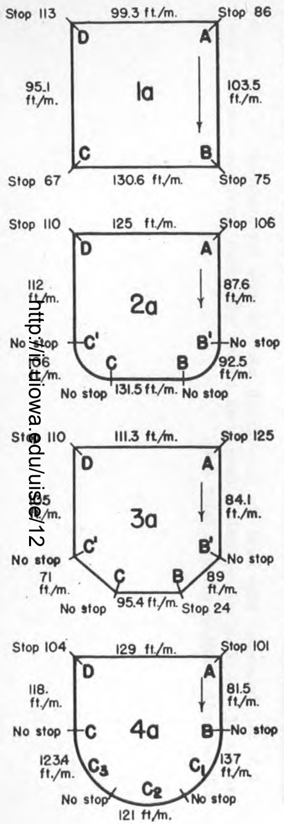
PATH No. 4 Distance = 36.92 inches, Time = 2.0138 sec., Av. Velocity = 91.8 ft./min.

	A ---------- B					B ---------- C				C ---------- D					D ---------- A				
	a	p	d	o	Total	C_1	C_2	C_3	Total	a	p	d	o	Total	a	p	d	o	Total
Time in Thousandths of a Second	163	133	0	0	296	308	282	232	822	0	195	62	92	349	139	183	92	133	547
% Time	55.0	45.0	0	0	100	37.5	34.3	28.2	100	0	55.8	17.8	26.4	100	25.4	33.5	16.8	24.3	100
Distance in Inches	2.12	2.98	0	-	5.1	5.44	5.44	5.44	16.32	0	4.19	.91	--	5.1	2.45	5.92	2.03	--	10.4
% Distance	41.5	58.5	0	-	100	33.3	33.3	33.3	100	0	82.1	17.9	--	100	23.6	56.9	19.5	--	100

In path No. 4 the subscripts C_1, C_2, and C_3 denote the first, second, and third equal divisions of the semi-circle, B to C.
Subscript a denotes periods of acceleration.
Subscript p denotes periods of constant velocity.
Subscript d denotes periods of deceleration.
Subscript o denotes periods of change of direction.

TABLE III RESULT SHEET

Velocities in feet per Minute — Time for Stops in Thousandths of a Second



PATH 1-a Total length of path, Distance = 40 inches, Time = 2.148 sec., Av. Velocity = 93 ft./min.

	A ---- B					B ---- C					C ---- D					D ---- A				
	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total
Time in Thousandths of a Second	231	147	106	75	559	156	132	92	67	447	261	158	106	113	638	150	167	101	86	504
% Time	41.4	26.3	18.9	13.4	100	34.9	29.5	20.6	15.0	100	40.9	24.8	16.6	17.7	100	29.8	33.1	20.0	17.1	100
Distance in Inches	3.55	4.55	1.90	--	10	3.23	4.47	2.30	--	10	3.06	4.82	2.12	--	10	2.81	5.38	1.81	--	10
% Distance	35.5	45.5	19.0	--	100	32.3	44.7	23.0	--	100	30.6	48.2	21.2	--	100	28.1	53.8	18.1	--	100

PATH 2-a Distance = 37.89 inches, Time = 1.970 sec., Av. Velocity = 96 ft./min.

	A ---- B'					B'-B	B ---- C					C-C'	C' ---- D					D ---- A				
	a	p	d	o	Total	Total	a	p	d	o	Total	Total	a	p	d	o	Total	a	p	d	o	Total
Time in Thousandths of a Second	299	129	0	0	428	212	112	80	0	0	192	185	65	170	100	110	445	167	164	69	106	506
% Time	69.9	30.1	0	0	100	100	58.4	41.6	0	0	100	100	14.6	38.2	22.5	24.7	100	33.0	32.4	13.6	21.0	100
Distance in Inches	4.15	3.35	0	-	7.5	3.92	2.56	2.49	0	-	5.05	3.92	1.26	4.20	2.04	--	7.5	3.30	5.20	1.50	--	10
% Distance	55.4	44.6	0	-	100	100	50.6	49.4	0	-	100	100	16.8	56.0	27.2	--	100	33.0	52.0	15.0	--	100

PATH 3-a Distance = 38.05 inches, Time = 2.29 sec., Av. Velocity = 83.1 ft./min.

	A ---- B'					B' ---- B					B ---- C					C ---- C'					C' ---- D					D ---- A				
	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total	a	p	d	o	Total
Time in Thousandths of a Second	190	179	77	0	446	143	104	0	24	271	125	90	0	0	215	181	122	0	0	303	173	133	47	110	462	236	143	87	125	590
% Time	42.6	40.1	17.3	0	100	52.7	38.4	0	8.9	100	58.1	41.9	0	0	100	59.7	40.3	0	0	100	37.4	28.7	10.2	23.7	100	39.9	24.2	14.7	21.2	100
Distance in Inches	2.40	3.92	1.18	-	7.5	2.09	2.31	0	--	4.4	1.82	2.28	0	-	4.1	2.30	2.00	0	-	4.3	3.36	3.18	.87	--	7.4	3.69	4.54	2.12	--	10.35
% Distance	32.0	52.3	15.7	-	100	47.5	52.5	0	--	100	44.4	55.6	0	-	100	53.5	46.5	0	-	100	45.3	42.9	11.8	--	100	35.6	43.9	20.5	--	100

PATH 4-a Distance = 36.92 inches, Time = 1.779 sec., Av. Velocity = 104 ft./min.

	A ---- B					B ---- C				C ---- D					D ---- A				
	a	p	d	o	Total	C_1	C_2	C_3	Total	a	p	d	o	Total	a	p	d	o	Total
Time in Thousandths of a Second	244	69	0	0	313	198	225	220	643	0	95	121	104	320	168	176	58	101	503
% Time	78.0	22.0	0	0	100	30.8	35.0	34.2	100	0	29.7	37.8	32.5	100	33.4	35.0	11.5	20.1	100
Distance in Inches	3.11	1.99	0	-	5.1	5.44	5.44	5.44	16.32	0	2.52	2.58	--	5.1	3.04	6.02	1.35	--	10.4
% Distance	61.0	39.0	0	-	100	33.3	33.3	33.3	100	0	49.4	50.6	--	100	29.2	57.8	13.0	--	100

In path No. 4 the subscripts C_1, C_2, and C_3 denote the first, second, and third equal divisions of the semi-circle, B to C.

Subscript a denotes periods of acceleration.
Subscript p denotes periods of constant velocity.
Subscript d denotes periods of deceleration.
Subscript o denotes periods of change of direction.

rest period the operator was seated in front of path 2, and a practice period of 50 cycles was allowed. Then ten consecutive cycles were recorded. In a like manner records were made for paths 3 and 4.

The second part of the study was similar to the first part except that the fiber boards were inverted, i. e., the face or straight side of the path in each case was placed away from the operator instead of next to him. For the position of the motion paths 1a, 2a, 3a, and 4a see figures in Table III.

Due to the great amount of time required in analyzing the records made by the kymograph, only the results obtained from one operator are presented here.[9]

Results.—Tables II and III give the results from five consecutive cycles of each of the four paths in the normal position and in the inverted position. Summarized data from the tables are shown on the motion paths at the left hand side of the tables.

Other data are taken from Tables II and III and arranged for easier interpretation in Tables IV to VIII.

Conclusions.

1. The average velocity of the hand moving through paths involving continuous curved motions was considerably higher than on those involving a number of abrupt changes in direction. Table IV shows paths 2 and 4 to have higher velocities than paths 1 and 3.

2. In general, the average velocity of the hand on a path, or the amount of time required for motion along equal distances depends upon:

(a) the number of abrupt changes of direction involved (The per cent of path time used for change direction varies with the number of abrupt changes of direction provided they all involve the same degree angle. See Table V.);

(b) the angle involved in each change of direction (The time required for an abrupt change of direction varies

9 A. B. Cummins, who built the kymograph used in this investigation, is now in the process of analyzing and compiling data from twelve additional operators and the results will be made available at some later date.

in inverse fashion with the angle involved. See Table VI.); and

(c) the length of the segment between the abrupt changes of direction. (See Tables II and III.)

3. Motions in a horizontal direction (i. e., parallel to the front of the operator's body) on a plane parallel to the floor tended to produce higher average velocities than similar type motions in a vertical direction (i. e., perpendicular to the front of the operator's body) in the same plane. See Table VII.

4. The lower classification[10] of motions (i. e., those involving mainly the elbow joint) tended to produce higher average velocities over similar paths than motions of a higher classification, (i. e., those involving mainly the shoulder joint). Table VIII gives the average velocities of segments and combinations of segments

TABLE IV

AVERAGE VELOCITIES FOR THE PATHS IN FEET PER MINUTE AND IN PER CENT OF THE AVERAGE VELOCITY FOR THE SQUARE PATH (PATHS 1 AND 1a)

Path (Normal)	Velocity in Ft. Per Min.	Ratio Per Cent	Path (Inverted)	Velocity in Ft. Per Min.	Ratio Per Cent
1	81.5	100*	1a	93.	100*
2	88.6	109.	2a	96.	103.2
3	73.1	89.8	3a	83.1	89.5
4	91.8	112.8	4a	104.	112.

*100 per cent for square path.

TABLE V

THE PER CENT OF TOTAL PATH TIME USED FOR ABRUPT CHANGES OF DIRECTION; THE ANGLE INVOLVED IN THE CHANGES; AND THE NUMBER OF CHANGES INVOLVED IN THE PATHS

Path	Number of Abrupt Changes			Path	Number of Abrupt Changes		
(Normal)	90°	135°	Per Cent*	(Inverted)	90°	135°	Per Cent
1	4	0	17.9	1a	4	0	15.9
2	2	0	10.1	2a	2	0	11.0
3	2	3	12.2	3a	2	3	11.3
4	2	0	11.2	4a	2	0	11.5

*Per cent of total path time used for abrupt changes of direction.

10 For classification of motions see "Motion and Time Study," by Ralph M. Barnes, John Wiley & Sons, New York, p. 116, 1937.

based on time used for motion only, and expressed in both feet per minute and in per cent of the velocity (based on time used for motion only) for the path in which the segments occurred. Similar segments are compared.

TABLE VI

TIME REQUIRED FOR ABRUPT CHANGES OF DIRECTION FOR 90 AND 135 DEGREE ANGLES

Angle in Degrees	Number of Cases	Average Time in Thousandths of a Second
90	100	102.3
135	40	9.0

TABLE VII

VELOCITIES IN FEET PER MINUTE FOR TEN INCH STRAIGHT LINE SEGMENTS IN PATH; 1 AND 1a

Path	Horizontal			Vertical		
	B–C	D–A	Total	A–B	C–D	Total
1	98.4	115.5	213.9	92.0	94.4	186.4
1a	130.6	99.3	229.9	103.5	95.1	198.6
Average			221.9			192.5

TABLE VIII

COMPARISON OF VELOCITIES OBTAINED FOR SIMILAR SEGMENTS WITH LOW AND HIGH CLASSIFICATION MOTIONS. VELOCITIES ARE BASED ON TIME USED FOR MOTION ONLY AND ARE IN FEET PER MINUTE. PERCENTAGES ARE BASED ON AVERAGE VELOCITY OBTAINED FOR EACH PATH FROM TIME USED FOR MOTION ONLY

Segment	Path	Mainly Elbow Motions		Path	Mainly Shoulder Motions	
		Velocity	Per Cent		Velocity	Per Cent
D–A & B–C	1	115.5	116.3	1	98.4	99.0
B–C & D–A	1-a	130.6	118.0	1-a	99.3	89.8
D–A	2	120.6	122.3	2-a	125.0	115.4
D–A	3	109.5	131.0	3-a	111.3	118.9
D–A	4	126.0	122.0	4-a	129.0	110.2
B′–C′	2-a	109.2	101.0	2	90.7	92.0
B′–C′	3-a	81.1	86.5	3	70.6	84.6
B–C	4-a	127.1	118.6	4	100.5	97.4

PART II

A STUDY OF HAND MOTIONS USING THE PHOTO-ELECTRIC CELL AND THE KYMOGRAPH

INVESTIGATION NO. 3: A STUDY OF THE TIME REQUIRED TO POSITION PINS IN BUSHINGS WITH BEVELED HOLES

Object.—The object of this investigation was to determine the effect on positioning time of changing the amount of bevel surrounding a hole in a steel bushing into which a pin was to be inserted: A, when there was only a small clearance (0.002″) between the pin and the hole (This situation is analogous to a "go" gauge for gauging small pins, shafts, and similar parts.); and B, when there was a considerable clearance (0.010″) between the pin and the hole. (This situation is analogous to the assembly of pins, bolts, screws, etc., in holes.)

Parts Used.—The pins used were made of cold rolled brass rod

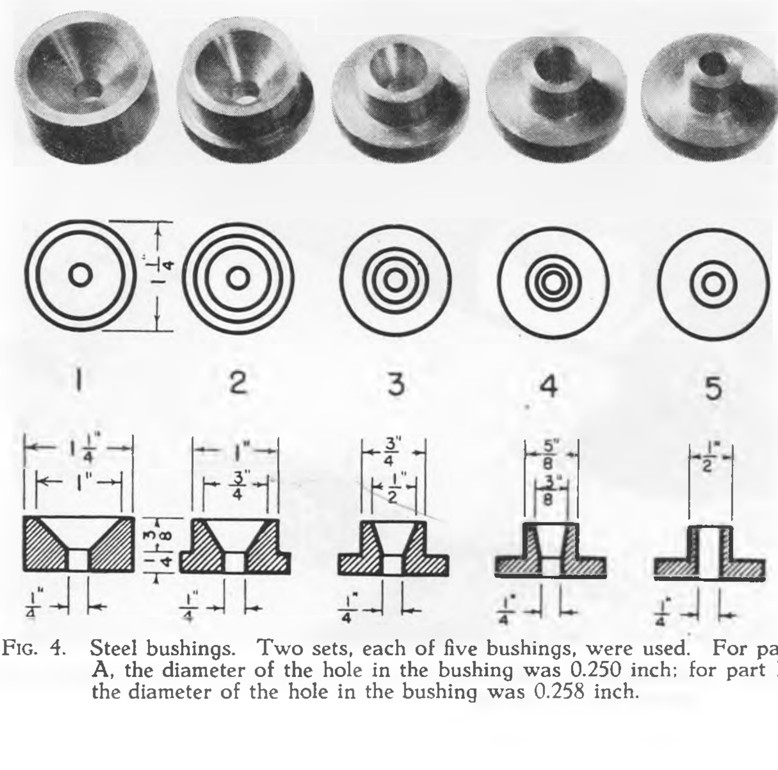


FIG. 4. Steel bushings. Two sets, each of five bushings, were used. For part A, the diameter of the hole in the bushing was 0.250 inch; for part B, the diameter of the hole in the bushing was 0.258 inch.

polished to 0.248 $^{+0.0015}_{-0.0005}$ inch in diameter, 1.25 inches long, and with 1/32 inch bevel at each end.

Five steel bushings were made of cold rolled stock turned to the dimensions shown in Fig. 4. The bevel was carefully polished and the holes were drilled, reamed and polished to a diameter of 0.250 $^{+0.001}_{-0.000}$ inch for part A of the study, which gave a clearance of 0.002 inch between the pin and the hole.

An identical set of bushings were used for part B of the study with the exception that the holes in this set were 0.258 $^{+0.001}_{-0.000}$ inch in diameter which gave a clearance of 0.010 inch between the pin and the hole.

Equipment Used in Making the Studies.—In order to simulate operating conditions in the factory, the interruption of a beam of light falling on a photoelectric cell was used to determine the end of the transport loaded and the beginning of the position therbligs,

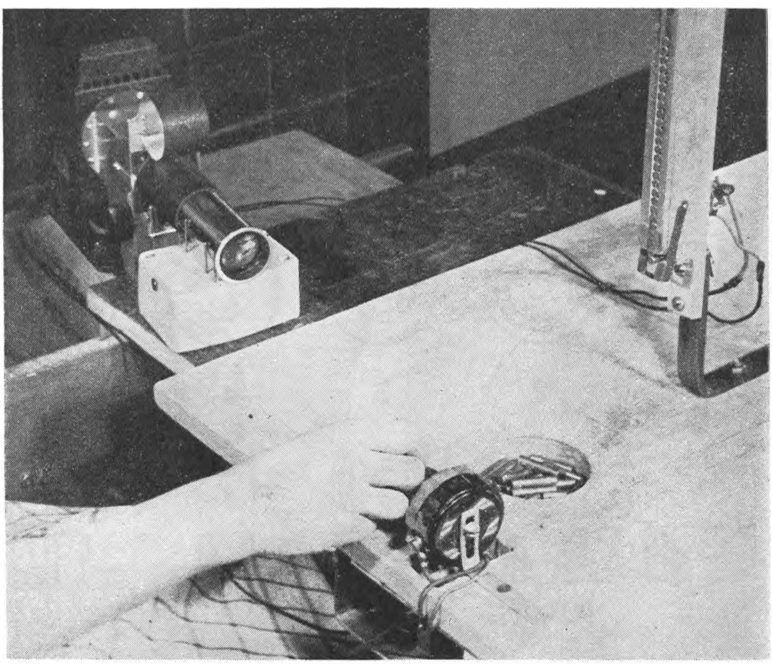


FIG. 5. Arrangement of the work place for the pin assembly. Operator inserting pin in bushing.

since this device did not interfere with the smooth and natural performance of the operator.

The work place was arranged as shown in Figs. 5 and 6. Fig. 4

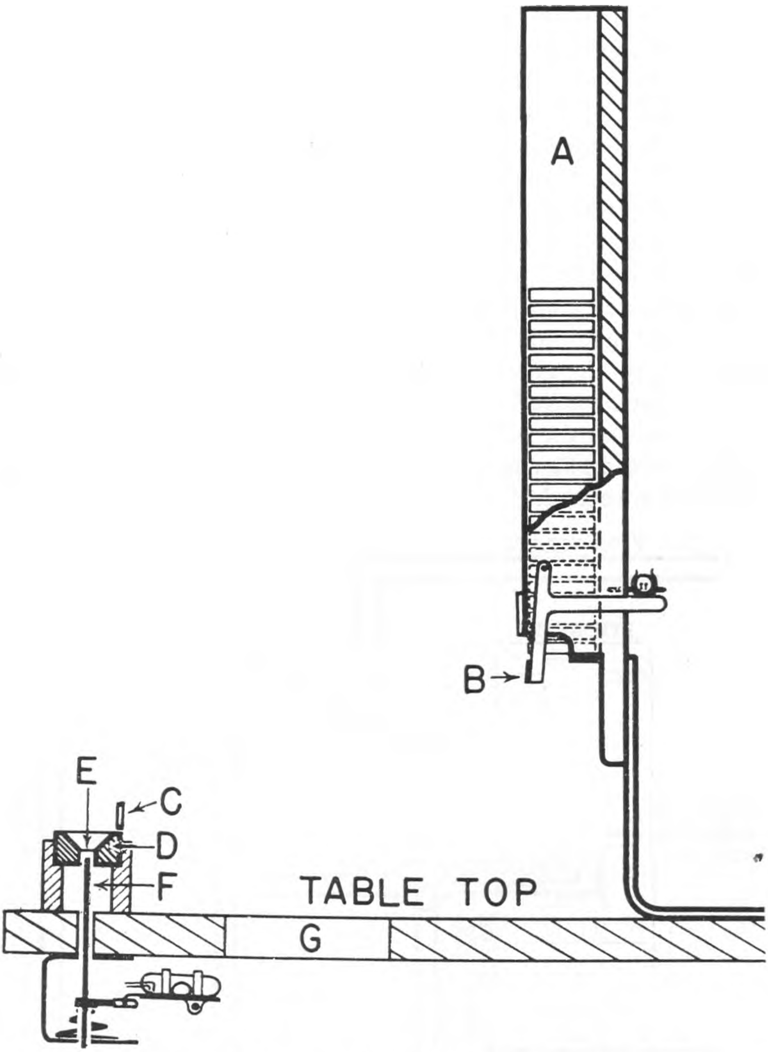


FIG. 6. Cross section of the work place for the pin assembly. A—magazine for pins; B—thumb-trip connected to a mercury switch; C—beam of light falling on photoelectric cell; D—steel bushing; E—hole in bushing; F—plunger connected to mercury switch; G—bin in table top.

shows the five different bushings that were used and Fig. 7 shows the wiring diagram.

The apparatus consisted of a magazine A (Fig. 6) containing 50 brass pins. The sides of the lower end of the magazine were cut away so that the bottom pin could easily be grasped by the thumb and index finger of the right hand. A light metal bar B (Fig. 6)—called a thumb-trip—was mounted on the magazine and extended in front of the bottom pin. The thumb-trip was so arranged that the operator easily, and without interrupting his movement, pushed the trip back with his thumb as he grasped the bottom pin in the magazine. As the trip was pushed back it moved a mercury switch which in turn was connected to a solenoid operated pencil on the kymograph (See Figs. 7 and 8). The kymograph contained a strip of paper moving at uniform velocity under the solenoid operated pencils. A movement of the pencil point made a jog on the moving strip of paper (See Figs. 7 and 8) and since the paper moved at exactly 31.9 inches per second, distance between jogs on the paper indicated the time between the various motions or therbligs in a cycle. Readings were made in thousandths of a second.

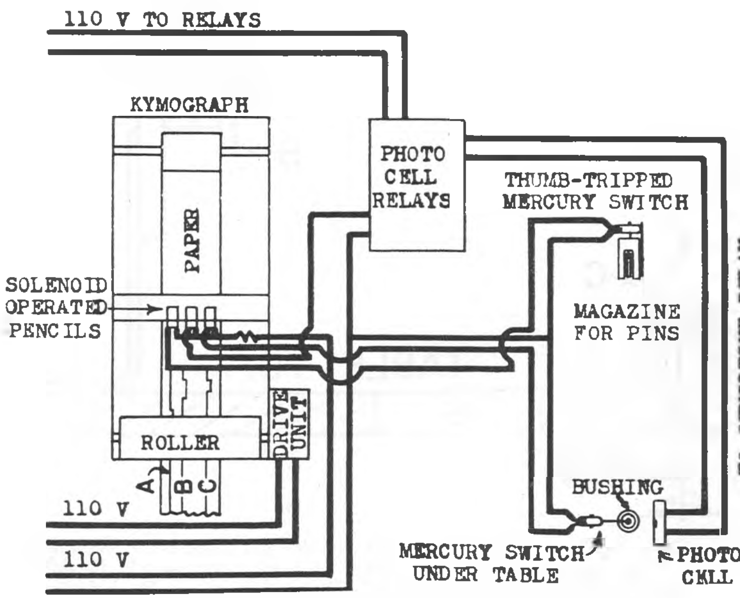


FIG. 7. Wiring diagram for the pin assembly.

Line A (Fig. 8) was made by the solenoid operated pencil connected to the thumb-tripped switch at the bottom of the magazine. Since the operator pushed this thumb-trip back when beginning to grasp the pin, the time that this circuit was closed was the time to grasp the pin. Although this included the first quarter inch of the transport loaded, this additional time was but a minor part of the total time and was practically uniform for all cycles. Thus $T_{G.}$ on line A of Fig. 8 was a measure of the time to grasp the pin.

The operator then carried the pin in his right hand toward the edge of the table and inserted it in hole E (Fig. 6) of the steel bushing D. As the operator withdrew the pin from the magazine it was in a horizontal position. As the pin was carried toward the hole the operator positioned it so that it was in a vertical position as it reached the edge of the bushing.

A beam of light C passed across the edge of the bushing and fell on a photoelectric cell mounted rigidly in a position directly to the right of the bushing. The light source was positioned so that the beam passed across the top of the bushing. A vertical slot 1/16 " wide and ½ " long was made in a black paper cap which covered the photoelectric cell. This slot was so positioned with respect to the center of the hole in the bushing that as the brass pin was carried from the magazine toward the hole it interrupted the beam of light when the pin was one-half inch from the center of the hole. This was kept constant for all five bushings. As the beam of light was cut off by the pin the solenoid operated pencil made a jog in line B (Fig. 8). The solenoid was operated through two relays connected to the photoelectric cell. The beginning of the jog was regarded as the beginning of the positioning time and the end of the transport loaded which began when the grasp ended. Thus $T_{T.L.}$ on line B of Fig 8 was a measure of the time required to carry (transport loaded) the pin to the edge of the bushing.

It is possible that there was a slight lag through the relays which would have caused the positioning time to have appeared shorter than it really was, but this effect would be the same for all five bushings and consequently would not affect the difference in positioning between bushings.

In order to measure the time to position the pin in the hole in the bushing, a plunger, directly connected to a mercury switch, was placed in the hole. The top of this plunger projected to within one-eighth inch of the lower edge of the beveled part of the bushing and the plunger could be depressed three-sixteenths inch by inserting the brass pin in the hole and pushing it down as far as it would go. The switch connected to the plunger actuated a solenoid operated pencil which drew line C on the moving strip of paper on the kymograph. (See Fig. 8.)

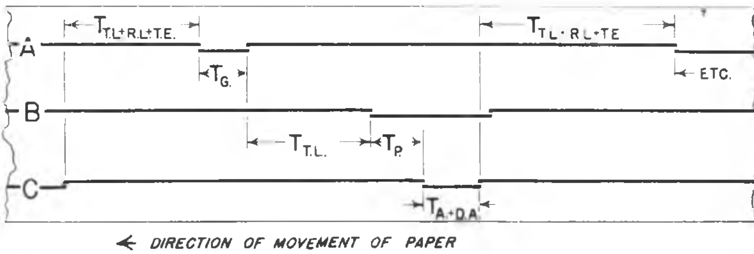


FIG. 8. Reproduction of record made by solenoid operated pencils on kymograph.

The plunger switch closed the circuit when the pin was three-sixteenths of an inch down in the hole and did not open the circuit until the pin had gone down another eighth of an inch and returned to within three-sixteenths of an inch of the top of the hole.

On bushing No. 5 (Fig. 4) there was no bevel and the vertical distance corresponding to the bevel on the other bushings was one-quarter inch in diameter, the same diameter as the hole. The plunger occupied the same position when used with bushing No. 5 as with the other bushings, hence, this extra quarter inch of travel through the upper portion of the bore was recorded as part of the positioning time as was the travel through the beveled sections of the other four bushings.

The beginning of the jog in line C (Fig. 8), made by a solenoid operated pencil connected to the plunger circuit, was regarded as the end of the positioning time. Thus $T_{P.}$ on line B (Fig. 8) was a measure of the time to position the pin in the hole.

Since the movement of the pin downward into the hole was considered as an assemble therblig and the withdrawal of the pin from the hole a disassemble therblig, $T_{A.+D.A.}$ on line C (Fig. 8) was a measure of these two therbligs.

After the pin was withdrawn from the hole it was carried away from the operator and dropped into a bin G in the table top, the hand continuing on to the magazine to grasp the next pin and so beginning another cycle of the operation.

Thus $T_{T.L.\ +\ R.L.\ +\ T.E.}$ on line A (Fig. 8) was a measure of the time to transport (transport loaded) the pin to the bin, release it, and move the hand (transport empty) on to the magazine.

The sequence of motions or therbligs for one cycle of the operation was as follows:

Steps Used in Inserting Pins in Bushings	Name of Therblig	Time for Therblig on Fig. 8
1. Remove one pin from magazine at B in Fig. 6	Grasp	$T_{G.}$
2. Carry pin to edge of bushing at C	Transport loaded	$T_{T.L.}$
3. Place pin in hole E of bushing D	Position	$T_{P.}$
4. Move pin down into hole E	Assemble	$T_{A.\ +\ D.A.}$
5. Withdraw pin from hole E	Disassemble	
6. Carry pin to hole G in table	Transport loaded	$T_{T.L.\ +\ R.L.\ +\ T.E.}$
7. Dispose of pin	Release load	
8. Move hand to magazine A	Transport empty	

Procedure.—Seven operators were used on each of the two parts of the study. The operators were instructed to grasp one pin at a time, carry it to the hole, turning the pin perpendicular by the time the hole was reached, insert the pin into the hole as far as it would go, withdraw it, drop the pin into the bin provided, grasp another pin and repeat the cycle until the magazine was empty.

Each subject was asked to do the task as rapidly as he could.

Previous to recording the data on the kymograph, each operator practiced 100 insertions with bushing No. 5. He then practiced 30 insertions with bushing No. 1 and the next 10 insertions were recorded without the operator pausing. The operator then practiced 30 insertions with bushing No. 2 and the next 10 insertions were recorded without the operator pausing. The procedure for bushings Nos. 1 and 2 was repeated with bushings Nos. 3, 4, and 5 and again with 5, 4, 3, 2, and 1 in that order. The data from 5 consecutive[11] cycles from each set of 10 were analyzed. The operators were all male college students.

Results.—The data were all taken from the paper passing under the solenoid operated pencils of the kymograph. Measurements were made to the nearest thousandth of a second and the data tabulated. The median value of the time required by each operator

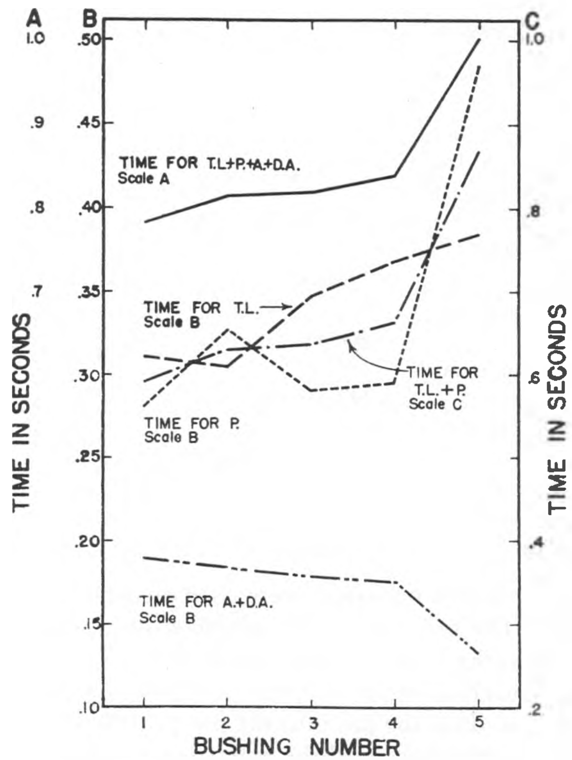


FIG. 9. Curves showing averages of median values (selected by total of time for transport loaded, position, assemble, and disassemble) of seven operators. The clearance between the pin and the hole in the bushing was 0.002 inch.

working with each bushing was selected by the total of the time for the transport loaded, position, assemble, and disassemble therbligs. Since there were ten analyzed cycles for each operator

[11] Occasionally an operator varied his movement path during the course of a run and failed to bring the pin across the beam of light falling on the photoelectric cell. Such a cycle was omitted since the positioning time could not be determined.

with each bushing, this necessitated averaging two cycles to obtain the median. The median value was used in preference to the average because the operators were only partly skilled and the median would be less affected by isolated extremely high or low values. Tables IX and X give a summary of these data, and the curves in Figures 9 and 10 show the results graphically.

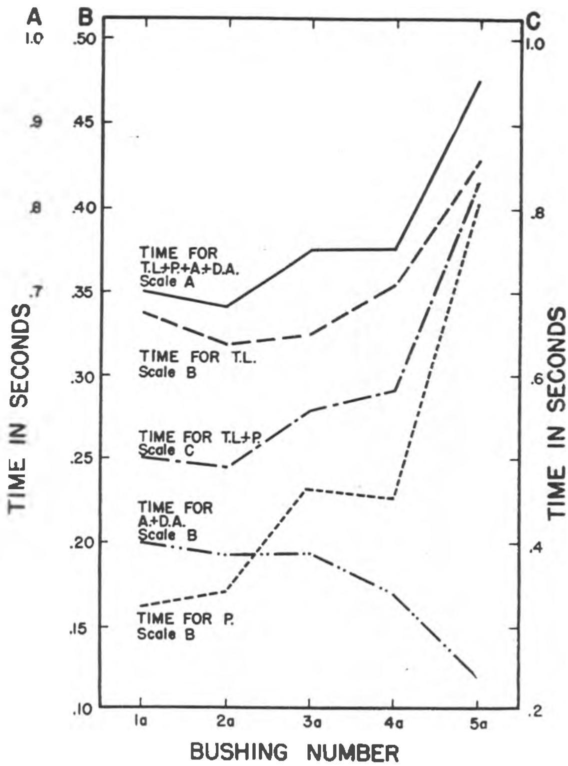


FIG. 10. Curves showing averages of median values (selected by total of time for transport loaded, position, assemble, and disassemble) of seven operators. The clearance between the pin and the hole in the bushing was 0.010 inch.

Conclusions.

Part A.—(The clearance between the pins and the holes in the bushing was 0.002 inch.)

1. The total time required to carry a pin to the bushing, position, insert, and remove it, increased as the amount of bevel

TABLE IX

RESULT SHEET

Medians selected by total of time for transport loaded, position, assemble, and disassemble for seven operators. The averages of the medians are also shown. The clearance between the pin and the hole in the bushing was 0.002 inch. Time in Thousandths of a Second.

Bushing No.	Operator No.	$T_{T.L.}$	$T_{P.}$	$T_{T.L.+P.}$	$T_{A.+D.A.}$	T*
1	1	397	244	641	189	830
	2	264	235	499	215	714
	3	277	308	585	180	765
	4	299	343	642	178	820
	5	272	254	526	202	728
	6	326	251	577	171	748
	7	340	333	673	195	868
	Av.	311	281	592	190	782
2	1	383	417	800	168	968
	2	262	307	569	228	797
	3	395	290	685	174	859
	4	245	305	550	183	733
	5	284	263	547	190	737
	6	285	291	576	160	736
	7	272	414	686	186	872
	Av.	304	327	630	184	815
3	1	536	178	714	169	883
	2	257	225	482	199	681
	3	391	257	648	167	815
	4	294	290	584	180	764
	5	351	252	603	185	788
	6	249	417	666	161	827
	7	352	414	766	193	959
	Av.	347	290	638	179	817
4	1	415	195	610	189	799
	2	265	346	611	185	796
	3	354	427	781	189	970
	4	437	215	652	158	810
	5	392	340	732	159	891
	6	351	263	614	153	767
	7	371	276	647	197	844
	Av.	369	295	664	176	840
5	1	430	452	882	139	1021
	2	271	613	884	156	1040
	3	541	438	979	181	1160
	4	414	534	948	82	1030
	5	372	469	841	78	919
	6	314	445	759	136	895
	7	346	441	787	160	947
	Av.	384	485	869	133	1002

*$T = T_{T.L.} + T_{P.} + T_{A.+D.A.}$

TABLE X

RESULT SHEET

Medians selected by total of time for transport loaded, position, assemble, and disassemble for seven operators. The averages of the medians are also shown. The clearance between the pin and the hole in the bushing was 0.010 inch.

Time in Thousandths of a Second

Bushing No.	Operator No.	$T_{T.L.}$	$T_{P.}$	$T_{T.L. + P.}$	$T_{A. + D.A.}$	T*
1a	1	419	87	506	202	708
	2	356	118	474	224	698
	3	373	191	564	240	804
	4	279	228	507	206	713
	5	283	207	490	233	723
	6	362	144	506	123	629
	7	296	162	458	173	631
	Av.	338	162	501	200	701
2a	1	275	198	473	193	666
	2	242	169	411	223	634
	3	361	141	502	239	741
	4	286	193	479	233	712
	5	325	210	535	141	676
	6	420	159	579	141	720
	7	325	127	452	179	631
	Av.	319	171	490	193	683
3a	1	278	302	580	110	690
	2	322	185	507	216	723
	3	248	354	602	222	824
	4	326	174	500	184	684
	5	393	180	573	200	773
	6	303	248	551	183	734
	7	407	178	585	245	830
	Av.	325	232	557	194	751
4a	1	311	281	592	125	717
	2	177	388	565	217	782
	3	383	196	579	228	807
	4	375	153	528	212	740
	5	373	196	569	185	754
	6	390	192	582	97	679
	7	478	178	656	127	783
	Av.	355	226	582	170	752
5a	1	471	313	784	50	834
	2	369	336	705	234	939
	3	614	402	1016	200	1216
	4	315	519	834	74	908
	5	320	462	782	84	866
	6	342	437	779	130	909
	7	575	347	922	74	996
	Av.	429	402	832	121	953

*$T = T_{T.L.} + T_{P.} + T_{A. + D.A.}$

surrounding the hole in the bushing was decreased from 45 (No. 1) to 0 (No. 5) degrees.

2. The sum of the time for the transport loaded and positioning increased as the amount of bevel surrounding the bushing hole decreased from 45 to 0 degrees.
3. The sum of the time for assemble and disassemble decreased as the bevel decreased from 45 to 0 degrees even though the length of the bearing surface (the one-quarter inch bore) was not increased except with hole No. 5 which had no bevel.
4. It appeared as though the times for the therbligs transport loaded, position, assemble and disassemble were interrelated, the last two named being affected by the speed of performance of the therbligs preceding it. Hence, it is suggested that the standard time for certain therbligs cannot be given as independent values since they may be influenced by other therbligs in the cycle.

Part B.—(The clearance between the pins and holes in the bushing was 0.010 inch.)

1. The total time required to carry a pin to the bushing, position, insert, and remove it, decreased as the amount of bevel surrounding the hole in the bushing decreased from 45 degrees (No. 1a) to 34 degrees (No. 2a), and increased as the bevel decreased from 34 degrees to 0 degrees (No. 5a).
2. The sum of the time for the transport loaded and positioning decreased as the amount of bevel surrounding the bushing hole decreased from 45 degrees to 34 degrees and increased as the bevel decreased from 34 degrees to 0 degrees.
3. The sum of the time for assemble and disassemble tended to decrease as the bevel decreased from 45 degrees to 0 degrees even though the length of the bearing surface (the one-quarter inch bore) was not increased except with bushing No. 5 which had no bevel.
4. It appeared as though the times for the therbligs transport loaded, position, assemble, and disassemble were interrelated, the last two named being affected by the speed of performance of the therbligs preceding it.

Investigation No. 4: A Study of the Time Required to Position Bars on Pins

Object.—The object of this investigation was to determine the effect of changing the shape of the tops of two steel pins on to which steel bars with two holes were assembled: A, when there was only a small clearance (0.003 inch) between the pin and the hole (This was analogous to a "go" gauge or to fairly accurate assembly work.); and B, when there was a considerable clearance (0.011 inch) between the pin and the hole. (This was analogous to rough assembly work.)

Parts Used.—The bars used in both parts of the study were made of cold rolled steel with the dimensions as shown in Fig. 11. For part A the two holes were drilled and reamed to a diameter of 0.250 inch. Thus the holes were 0.003 inch larger than the diameter of the pins. For part B of the study the bars were identical with those used in part A except that the holes were drilled and reamed to a diameter of 0.258 inch. Thus in this case the holes were 0.011 inch larger than the diameter of the pins.

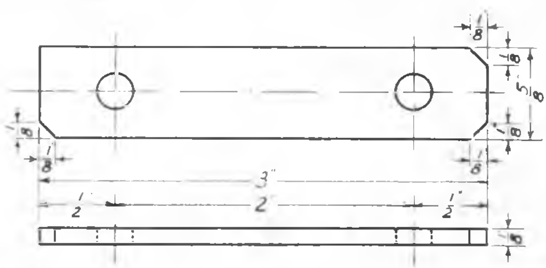


Fig. 11. Steel bar made from one-eighth inch cold rolled stock.

Five sets or pairs of pins (called "pin sets") were used in the study. Each pair of pins was permanently set in a heavy steel base. The pins were uniform in diameter and cylindrical in shape. The same five pin sets were used in both part A and B of the study.

The dimensions of the pin sets, their shape, and the number by which they are referred to are given in Fig. 12.

Equipment Used in Making the Study.—Much the same apparatus was used in this study as in the preceding one (Investiga-

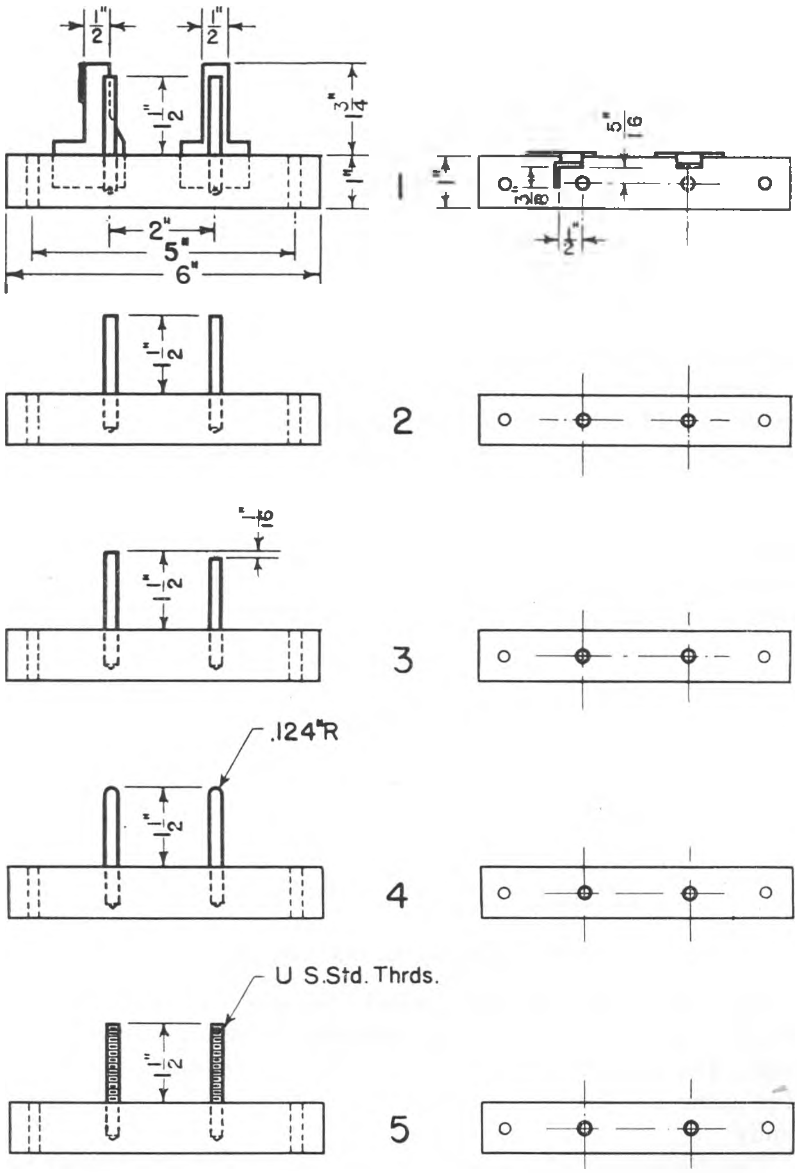


FIG. 12. Pin sets. No. 1—with guide at left hand end and back of pins. Smooth pins with square ends and of equal height; No. 2—smooth pins with square ends and of equal height; No. 3—smooth pins with square ends and of unequal height; No. 4—smooth pins with round ends and of equal height; No. 5—threaded pins with square ends and of equal height.

tion No. 3). The work place was arranged as shown in Figs. 13 and 14. Figure 15 shows the wiring diagram.

The apparatus consisted of a supply of eight bars which were loosely stacked on two pins at A in Fig. 14. The lever B, of light construction, was placed near the top and between the two pins. This lever was connected to a mercury switch C beneath the table. As each bar was removed the lever closed the circuit and moved a solenoid operated pencil on the kymograph (See Fig. 15). Line A (Fig. 16) was made by this pencil.

The operator carried one bar at a time from A (Fig. 14) and placed it on the pin set D. As the bar moved down onto the top of the pins it interrupted a beam of light coming from a projector at E and falling on a photoelectric cell at F. The photoelectric cell was connected through relays to a solenoid operated pencil on the kymograph. A vertical slit one-sixteenth inch wide and one-fourth inch long was made in a metal guard which covered the front of the photoelectric cell. The position of the light source and the position of the slit were so adjusted that the beam of light was interrupted as the bar came within one-eighth inch of the top of the left pin. This instant was considered as the end of the transport loaded therblig and the beginning of the position therblig.

The circuit of this solenoid remained closed until the bar was positioned onto the pins and until the top surface of the bar came flush with the top of the pins. The time that this circuit was closed was considered as the length of the positioning time. Line B in Fig. 16 was drawn by a pencil operated by this circuit. $T_{T.L.}$ on line B was a measure of the time to carry the bar from the supply at A to the pins at D. $T_{P.}$ was a measure of the time to position the bar on the pins and $T_{A. + R.L. + T.E. + G. + D.A.}$ was a measure of the time to assemble the bar onto the pins, release the bar, move the hand back to the supply of bars at A, grasp the next bar, and remove it from the small pins. Just as the bar left the pins at A the lever B tripped the mercury switch C and marked the beginning of the transport loaded therblig.

The sequence of motions or therbligs for one cycle of the operation was as follows:

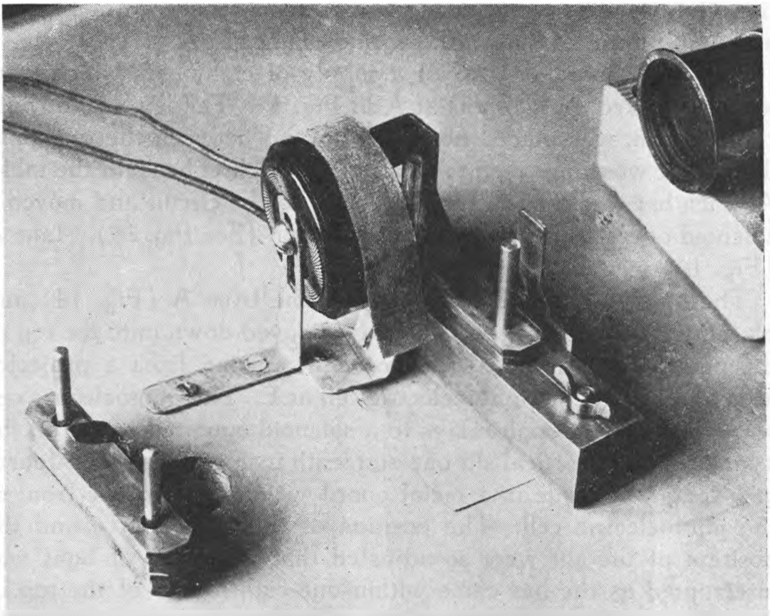


FIG. 13. Arrangement of the work place for the bar assembly.

Steps Used in Assembling Bars to Pin Sets	Name of Therblig	Time for Therblig in Fig. 16
1. Carry the bar from the supply at A to the pin set at D in Fig. 14	Transport loaded	TT.L.
2. Place bar on pin set at D	Position	TP.
3. Assemble bar to pin set at D	Assemble	TA. + R.L. + T.E. + G. + D.A.
4. Let go of bar	Release load	
5. Move hand back to supply of bars at A	Transport empty	
6. Grasp bar at A	Grasp	
7. Remove bar from thin pins at A	Disassemble	

Procedure.—Ten operators were used on each of the two parts of the study. Each operator was instructed to grasp one bar at a time with his right hand, lift the bar off of the thin pins that kept the bars in a stack, carry the bar to the pin set and assemble it.

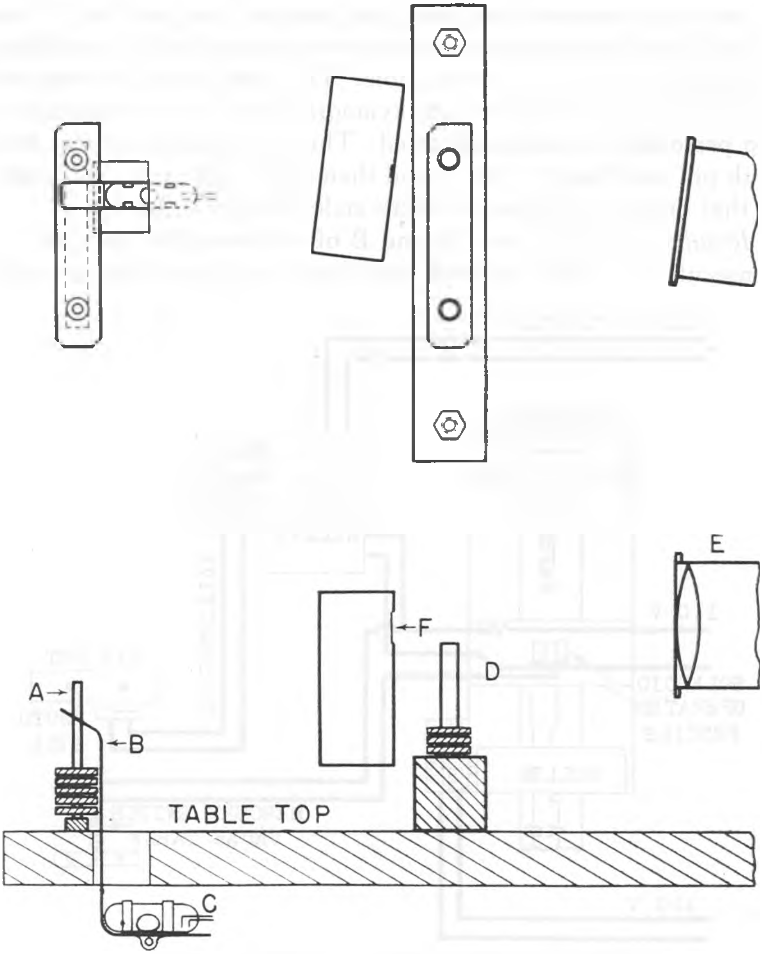


FIG. 14. Cross section of the work place for the bar assembly. A—one-eighth inch diameter pins holding the supply of bars to be assembled onto the pins of the pin set; B—trip lever connected to mercury switch under table top; C—mercury switch; D—pin set; E—source of light for photoelectric cell; F—slit in cover of photoelectric cell.

The operators were further instructed to use the same method of grasping at all times.

The operators practiced 48 assemblies with each of the five pin sets, making 240 assemblies in all, previous to the recording of any data on the kymograph. The operators practiced at pin sets Nos. 1, 2, 3, 4, and 5 in that order.

After an operator had had this practice, pin set No. 1 was again placed in position and the operator practiced 8 assemblies, doing them as fast as he was able. The time values for the next 8 cycles were recorded by the kymograph, these 8 cycles also being performed at maximum speed. This same procedure was used with pin sets Nos. 2, 3, 4, 5, and then again with 5, 4, 3, 2, and 1 in that order. All operators were male college students.

Results.—In both parts A and B of the study the data for five consecutive[12] cycles for each work spell with each pin set were

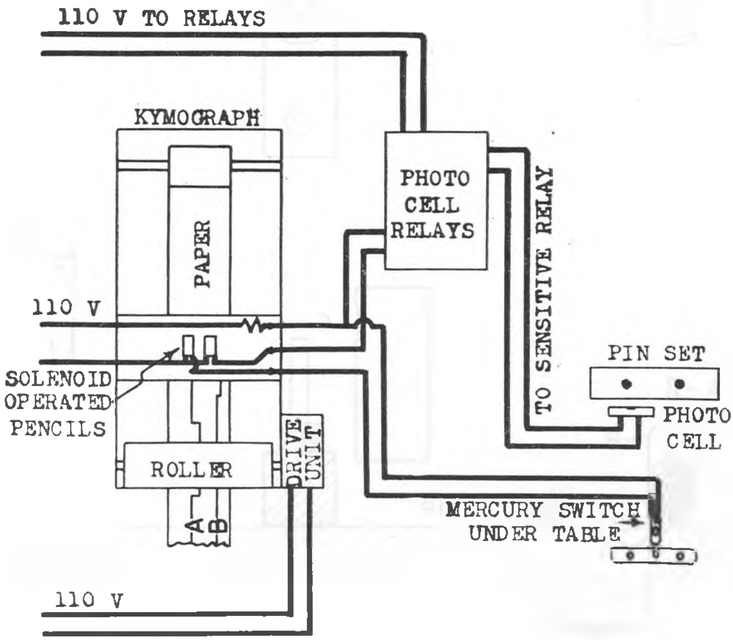


FIG. 15. Wiring diagram for the bar assembly.

analyzed. Since the subject proceeded from pin set No. 1 to 5 and then from set No. 5 back to 1, there were ten cycles for each pin set per operator. The method of analysis is shown in Fig. 16.

In both parts of the experiment, the median values were computed from the ten cycles with each set of pins for each operator because the operators were only partly skilled and the average values would be influenced more than the median by isolated ex-

12 The operator sometimes fumbled and such cycles were not included in the analyzed data.

tremely high or low values. These medians were computed on the basis of the sum of the transport loaded and positioning time, for each cycle. Since there were ten cycles in each set this necessitated averaging two cycles. The time for the rest of the cycle for both of these selected cycles was also averaged. It is to be noted that the median was not selected for each therblig individually but that two selected actual cycles were averaged.

Tables XI and XII give a summary of these data, and the curves in Figs. 17 and 18 show the results graphically.

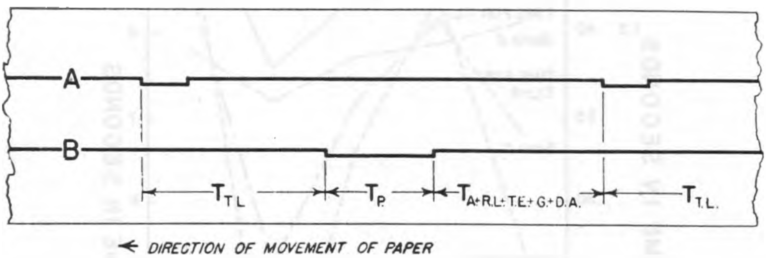


FIG. 16. Reproduction of record made by solenoid operated pencils on kymograph.

Conclusions.

Part A.—(The clearance between the pins and the holes in the bars was 0.003 inch.)

1. The pin set with the positioning guide (No. 1) produced a cycle 11% faster, a *positioning* time 35% less and a *transport loaded* time 3% greater than a cycle with identical pins without the guide (No. 2).
2. The lowering of the right hand pin one-sixteenth of an inch (No. 3) produced a cycle 13% faster, a *positioning* time 22% less and a *transport loaded* time 4% less than a cycle with similar pins of equal height (No. 2).
3. The rounding of the tops of the pins (No. 4) produced a cycle 23% faster, a *positioning* time 61% less and a *transport loaded* time 9% less than a cycle with pins with their tops square to the body of the pins (No. 2).
4. The cutting of threads on the pins (No. 5) produced a cycle 1% slower, a *positioning* time 11% greater and a

transport loaded time 0.5% less than a cycle with pins identical but without the threads (No. 2).

5. The pins with the rounded tops (No. 4) resulted in the fastest cycle, the shortest *positioning* time and the shortest *transport loaded* time.

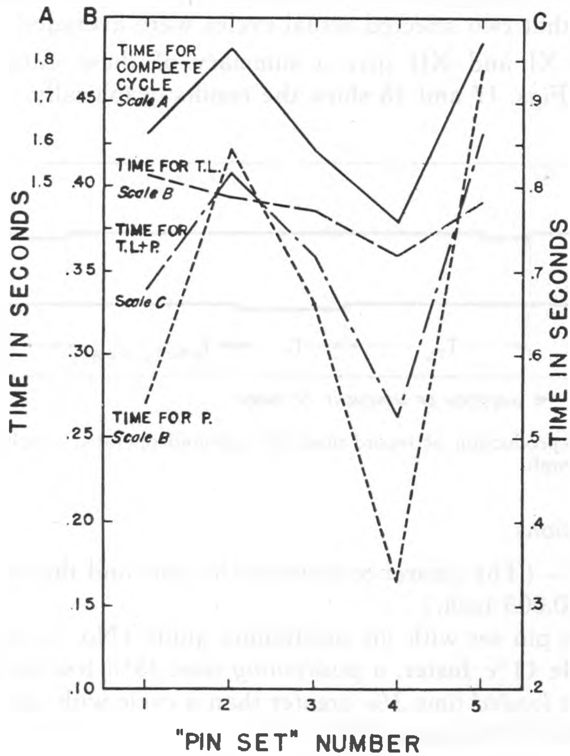


FIG. 17. Curves showing averages of median values (selected by total of time for transport loaded and position) of ten operators with the five pin sets. The clearance between the pins and the holes in the bar was 0.003 inch.

6. With the exception of the pins with the positioning guides (No. 1), the time for the *transport loaded* tended to vary with the *positioning* time as shown by Fig. 17 although no changes were made in the length or manner of this movement, indicating that a standard time for a *transport* cannot be specified as a standard time without considering the nature of the cycle in which it takes place.

Part B.—(The clearance between the pins and the holes in the bars was 0.011 inch.)

1. The pins with the positioning guide (No. 1) produced a cycle 15% faster, a *positioning* time 40% less and a *trans-*

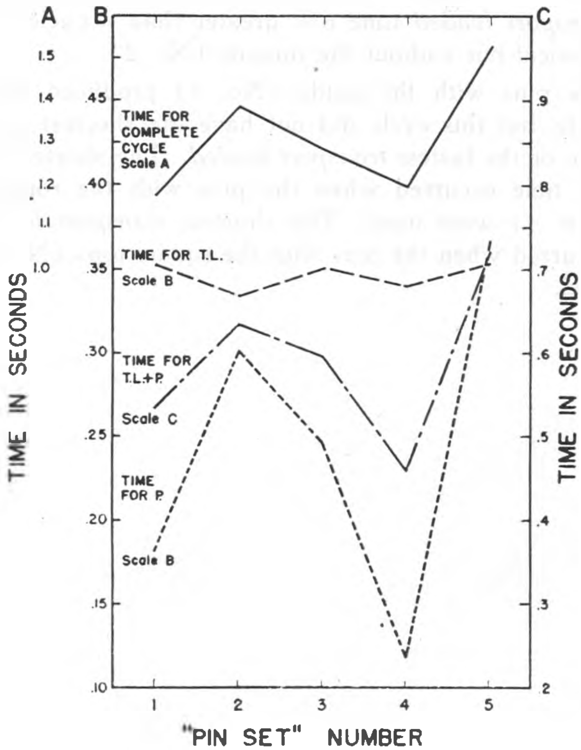


FIG. 18. Curves showing averages of median values (selected by total of time for transport loaded and position) of ten operators with the five pin sets. The clearance between the pins and the holes in the bar was 0.011 inch.

port loaded time 5% greater than a cycle with identical pins without the guide (No. 2).

2. The lowering of the right hand pin one-sixteenth of an inch (No. 3) produced a cycle 7% faster, a *positioning* time 18% less and a *transport loaded* time 5% greater than a cycle with similar pins of equal height (No. 2).
3. The rounding of the tops of the pins (No. 4) produced a

cycle 14% faster, a *positioning* time 60% less and a *transport loaded* time 2% greater than a cycle with pins with their tops square to the body of the pins (No. 2).

4. The cutting of threads on the pins (No. 5) produced a cycle 9% slower, a *positioning* time 22% greater and a *transport loaded* time 6% greater than a cycle with pins identical but without the threads (No. 2).
5. The pins with the guide (No. 1) produced the fastest cycle, but this cycle did not have the shortest *positioning* time or the fastest *transport loaded*. The shortest *positioning* time occurred when the pins with the rounded tops (No. 4) were used. The shortest *transport loaded* time occurred when the pins with the square tops (No. 2) were used.

TABLE XI

RESULT SHEET

Medians selected by total of time for transport loaded and position for ten operators. The averages of the medians are also shown. The clearance between the pins and the holes in the bar was 0.003 inch.

Time in Thousandths of a Second

Pin Set No.	Operator No.	$T_{T.L.}$	$T_{P.}$	$T_{T.L. + P.}$	$T_{A. + R.L. + T.E. + G. + D.A.}$	T*
	1	420	312	732	939	1671
	2	399	138	537	920	1457
	3	320	298	618	924	1542
	4	380	252	632	863	1495
	5	420	279	699	1087	1786
1	6	629	433	1062	1200	2262
	7	392	229	621	775	1396
	8	369	165	534	838	1372
	9	377	179	556	822	1378
	10	366	425	791	1068	1859
	Av.	407	271	678	944	1622
	1	399	685	1084	1158	2242
	2	312	162	474	880	1354
	3	358	506	864	1010	1874
	4	322	427	749	931	1680
	5	358	392	750	851	1601
2	6	564	412	976	1639	2615
	7	493	262	755	758	1513
	8	366	435	801	642	1443
	9	404	415	819	1166	1985
	10	360	538	898	1089	1987
	Av.	394	423	817	1012	1829
	1	404	462	866	1044	1910
	2	334	258	592	843	1435
	3	325	304	629	779	1408
	4	421	408	829	796	1625
	5	380	344	724	1003	1727
3	6	510	277	787	1094	1881
	7	361	326	687	788	1475
	8	391	362	753	725	1478
	9	396	336	732	704	1436
	10	352	231	583	922	1505
	Av.	387	331	718	870	1588
	1	403	240	643	1195	1838
	2	352	34	386	891	1277
	3	307	204	511	764	1275
	4	310	261	571	1250	1821
	5	343	160	503	837	1340
4	6	381	229	610	839	1449
	7	401	115	516	729	1245
	8	366	78	444	678	1122
	9	383	132	515	700	1215
	10	350	199	549	1035	1584
	Av.	360	165	525	892	1417
	1	420	591	1011	917	1928
	2	311	173	484	1235	1719
	3	332	552	884	1251	2135
	4	376	562	938	1414	2352
	5	357	472	829	933	1762
5	6	468	608	1076	964	2040
	7	384	347	731	802	1533
	8	406	516	922	746	1668
	9	435	320	755	764	1519
	10	432	572	1004	829	1833
	Av.	392	471	863	986	1849

*$T = T_{T.L.} + T_{P.} + T_{A.} + R.L. + T.E. + G. + D.A.$

Table XII

Result Sheet

Medians selected by total of time for transport loaded and position for ten operators. The averages of the medians are also shown. The clearance between the pins and the holes in the bar was 0.011 inch.

Time in Thousandths of a Second

Pin Set No.	Operator No.	$T_{T.L.}$	$T_{P.}$	$T_{T.L.+P.}$	$T_{A.+R.L.+T.E.+G.+D.A.}$	T*
	1	337	282	619	612	1231
	2	307	319	626	525	1151
	3	349	130	479	707	1186
	4	378	265	643	722	1365
	5	396	104	500	583	1083
1a	6	281	216	497	708	1205
	7	362	109	471	683	1154
	8	351	112	463	597	1060
	9	360	168	528	635	1163
	10	398	109	507	635	1143
	Av.	352	181	533	641	1174
	1	355	363	718	700	1418
	2	303	319	622	703	1325
	3	320	284	604	892	1496
	4	374	327	701	1020	1721
	5	332	296	628	624	1252
2a	6	300	243	543	819	1362
	7	352	275	627	694	1321
	8	317	343	660	698	1358
	9	292	407	699	652	1351
	10	395	151	546	717	1263
	Av.	334	301	635	752	1387
	1	378	140	518	661	1179
	2	336	335	671	750	1421
	3	278	239	517	469	986
	4	421	395	816	780	1596
	5	330	378	708	684	1392
3a	6	286	206	492	766	1258
	7	374	201	575	672	1247
	8	319	202	521	773	1294
	9	380	221	601	652	1253
	10	407	144	551	704	1255
	Av.	351	246	597	691	1288
	1	376	69	445	715	1160
	2	362	158	520	664	1184
	3	318	62	380	710	1090
	4	369	136	505	956	1461
	5	326	182	508	609	1117
4a	6	265	156	421	758	1179
	7	353	144	497	770	1267
	8	332	156	488	738	1226
	9	330	76	406	664	1070
	10	368	53	421	793	1214
	Av.	340	119	459	738	1197
	1	438	419	857	708	1565
	2	297	611	908	1093	2001
	3	327	243	570	730	1300
	4	422	298	720	828	1548
	5	367	493	860	657	1517
5a	6	292	396	688	959	1647
	7	389	308	697	773	1470
	8	324	277	601	721	1322
	9	331	469	800	744	1544
	10	358	162	520	731	1251
	Av.	354	368	722	794	1516

*$T = T_{T.L.} + T_{P.} + T_{A.} + R.L. + T.E. + G. + D.A.$

PART III

A STUDY OF HAND MOTIONS USING AN ELECTRICAL PURSUIT BOARD

INVESTIGATION No. 5: A STUDY OF RHYTHM IN HAND MOTIONS

Object.—The object of this investigation[13] was to evaluate the effect of changing the temporal pattern of therbligs in a given cycle of hand motions taking place in a given period of time, or more specifically, to determine the results of making a regular cycle of hand motions rhythmical without changing the physical aspects of the task.

Rhythm, in the psychological sense as it is used in this study, may be explained as follows: "If, without counting, one gives attention to the movements of the body and limbs while dancing, walking rapidly or running, he will readily perceive a fairly recurrent pattern of movements. Similarly the uniform puffs of a locomotive seem naturally to fall into rhythmical groups of two or of four puffs. *Rhythm* is the perception of groups or patterns of successive impressions, the members of which are perceived to be consistently different in some quantitative aspect . . . With this variation comes subordination and synthesis of the elements into groups."[14]

A series of cycles of motions accompanied by a feeling of grouping, that is, perceived as a *series of distinct, separated cycles,* will, in this study, be referred to as *rhythmical work.* The separation may be caused by either a momentary pause or a momentary relaxation of attention.

Rhythm is sometimes interpreted in a second way. It may be understood to mean merely a regular repetition of a series of motions. Thus, the reference is often made to the "rhythm" of turning a crank or of feeding material into a machine. In this study, a smooth, even, unaccented, regular repetition of a cycle of motions unaccompanied by a feeling of grouping will be referred to as *regular work.*

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13 From "Rhythm in Hand Motions," a University of Iowa Master's thesis by Marvin E. Mundel, February, 1938.

14 Boring, E. G., H. S. Langfeld, H. P. Weld and others, "Psychology, A Factual Textbook," p. 256, John Wiley and Sons, Inc., New York, 1935.

There has been considerable discussion of the merits of rhythmic work over merely regular work. One finds many references in the literature such as the following:

"Rhythm makes work easier as well as more enjoyable, because each effort is followed by a corresponding rest. The worker is physiologically attuned to rhythm; it is his biological heritage."[15]

"There is fundamental economy in rhythmical performance in that we get a repetition of the act without necessarily a repetition of the impulse."[16]

This study was made to obtain information bearing on the following questions:

1. Is the rhythmical method preferred to the merely regular method of doing the same task?
2. Does rhythmical work create less fatigue than merely regular work, (defining fatigue as a reduced capacity for activity resulting from previous activity)?
3. Does rhythmical work make for more automaticity than merely regular work?
4. Is the rhythmical work more efficient than merely regular work in that the worker can produce more work in a given period of time when working rhythmically?

Equipment Used in Making the Study.—The situation involved in this experiment consisted of a cycle composed of three use therbligs with a transport loaded and a position therblig between each two.

The actual task consisted of sitting at a table (See Fig. 19) and carrying, with the right hand, an electrode made of a one-sixteenth inch diameter copper rod set in a convenient wooden holder and attached to a very flexible wire, clockwise around a path the shape of a right triangle with sides of 5 inches, 10 inches, and 11.5 inches, and inserting the electrode into the one-quarter inch holes in the thin metal plates at the vertices of the triangle. This path was in the plane of the table top.

The electrode could only be inserted into the holes when a metal plate, covering their underside, was drawn back, this being done electrically, one hole at a time, to form a definite time pat-

15 Watkins, G. S., Labor Management, p. 551, A. W. Shaw Co., New York, 1928.

16 Burtt, H., "Psychology and Industrial Efficiency," p. 122, D. Appleton and Co., New York, 1931.

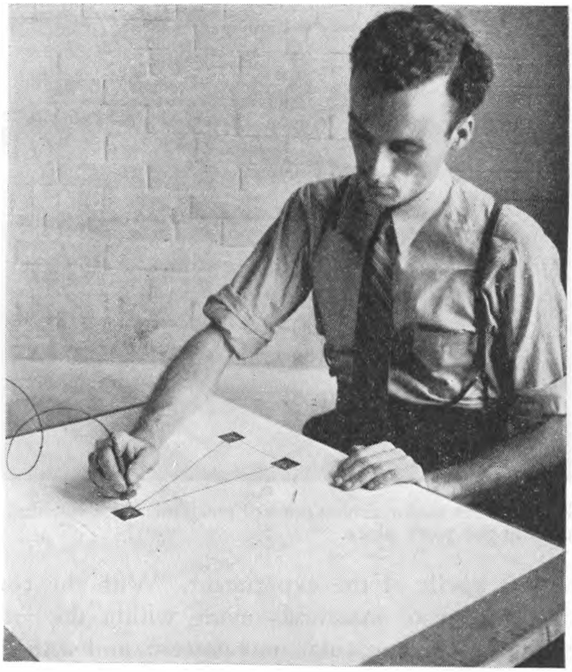

FIG. 19. Arrangement of work place—operator working.

tern of the possible use therbligs or insertions. Each successful insertion was recorded on an electrical counter, one for each hole, each connected to the electrode and to a copper plate set three-eighths of an inch below the upper surface of a hole. (See Figs. 19 and 21). The time each hole was open was four-tenths of a second, this being somewhat longer than the actual time required to insert the electrode so as to give the operator some leeway to more closely approximate the flexibility of the time pattern of an industrial task. The time between the opening of the successive holes, which was the time for the *transport loaded,* or movement, was varied to give the different temporal patterns while the total cycle time remained constant at two seconds. The device to close and open the circuits which were used to open the holes was driven by a synchronous motor to keep all time values constant. (See Fig. 20.)

The maximum number of insertions was 30 sets of three holes or 90 insertions per minute which was 2,700 insertions for each of the

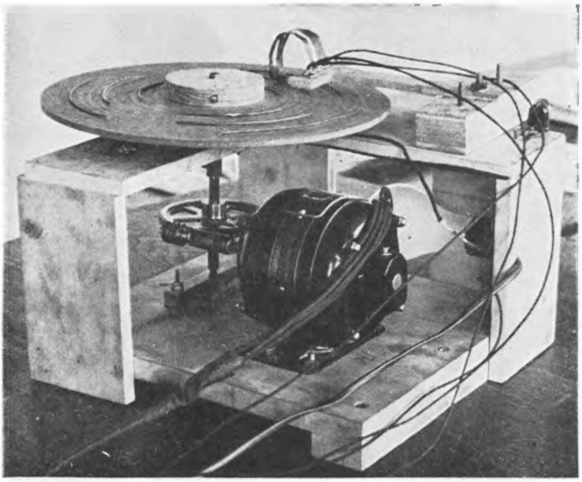

FIG. 20. Synchronous motor driven control mechanism for opening and closing holes at the work place.

half-hour work spells of the experiment. With the counters recording the number of insertions made within the intervals allowed for them by the particular time pattern, and with the number of insertions tabulated each minute of the work spell, the number of cycles missed could easily be determined for each minute of work.

The operators were instructed to stop as soon as they missed an insertion and to wait at that hole until the next opportunity to insert the electrode, to then do so, and continue around the path again. Thus each hole missed meant a cycle missed, which would be the case with an industrial operation where the failure to do a part of an operation at the time it is supposed to be done makes it impossible to do the rest of the operation; i. e., a girl filling boxes with a material certainly cannot perform the motions to fill the box which she failed to pick off the conveyor which brings them to and past her, until a box is again available; and similarly, an operator working at a punch press with steel-rule dies cannot push the die forward into the press until she has performed the motions necessary to arrange the material, to be punched, upon the die.

Procedure.—The operators first practised for one-half hour at inserting the electrode into the holes with the holes held open, so that they could gain a feeling of the spacial relationships of the movements involved. They then rested for fifteen minutes and were afterwards instructed as follows:

"The holes in the Pursuit Board will now be shut. (The pins holding the thin metal plates from covering the undersides of the holes were removed.) The holes will be opened during the run one at a time, one after the other, from this electrical control device. (The control device resting about ten feet away and behind the operator was pointed out to him.) You will try to insert the electrode into the holes when they are open, going from hole to hole, clockwise around the path. You will try to fit your movements as closely as possible into the time pattern suggested by the

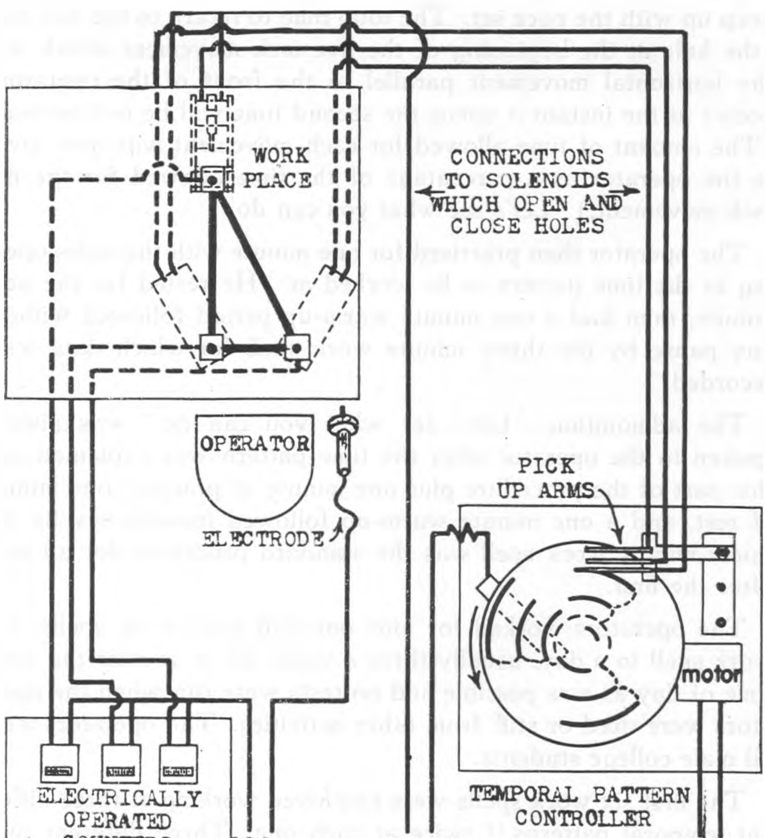

FIG. 21. Wiring diagram for rhythm studies.

openings of the holes by inserting the electrode into the holes as soon as possible after they are open. They will open for but a short period each time. You need only to hit or touch the bottom plate, withdraw the electrode and go towards the next hole, touch into that, and continue around. If you try to insert the electrode into a hole before it opens you will merely prevent it from opening. Only the insertions of the electrode made while the hole is open will register on the counters. If you fail to insert the electrode into any hole while it is open, do not move towards the next hole but wait at the hole missed until the next opportunity for insertion is presented to you; then make the insertion and continue around the path. You will try not to let this happen. Do your best to keep up with the pace set. The total time to return to the first hole (the hole at the beginning of the five inch movement which was the horizontal movement parallel to the front of the operator's body) at the instant it opens the second time will be two seconds. (The amount of time allowed for each movement was now given to the operator as a percentage of the time allowed for the five inch movement.) Let's see what you can do!"

The operator then practised for one minute with the holes opening in the time pattern to be worked at. He rested for the next minute, then had a one minute warm-up period followed without any pause by the thirty minute work spell for which data were recorded.

The admonition, "Let's see what you can do," was always spoken to the operator after the time pattern was explained and this part of the procedure plus one minute of practice, one minute of rest, and a one minute warm-up followed immediately by the thirty minute work spell was the standard procedure for all runs after the first.

The operators worked for nine one-half hour work spells, one work spell to a day, usually three a week, all at as near the same time of day as was possible and no tests were run when the operators were tired or stiff from other activities. The operators were all male college students.

The first six work spells were employed working at three different temporal patterns,[17] twice at each one. Three different tem-

[17] These three temporal patterns were, with the time for the 5 inch movement as the

poral patterns were presented to each operator for the first three work spells and then again presented in reverse order for the next three work spells. No more than two operators worked at any one of the six possible orders of presentation of the three different arrangements.

The results from these first six work spells showed the following:

1. In most cases the operators showed a constant improvement in the number of successful cycles from work spell to work spell.
2. None of the temporal patterns gave a very distinct feeling of rhythm.

Consequently the first six work spells were considered preliminary.

Work spells seven, eight, and nine were the same for all operators and were as follows:

Work spell No. 7 allowed, with the time for the 5 inch movement as the base of 100 per cent, 110 per cent for the 10 inch movement and 200 per cent for the 11.5 inch movement. This allowed the operator to work with constant effort over the cycle of three insertions and then either make a comparatively slow return movement to the first hole or to return rapidly and pause an instant before starting a new cycle.

Work spell No. 8 allowed, with the time for the 5 inch movement as the base of 100 per cent, 110 per cent for the 10 inch movement and 115 per cent for the 11.5 inch movement. (This was the same as the previous pattern A. See footnote at bottom of page.)

Work spell No. 9 was a repetition of the conditions of work spell No. 7.

Since the first six work spells usually showed an improvement from work spell to work spell regardless of the temporal pattern and since none of the patterns gave a very effective feeling of grouping, while work spells Nos. 7, 8, and 9 were free from this

base of 100 per cent:

Pattern A—110% for the 10 inch movement
115% for the 11.5 inch movement
Pattern B—200% for the 10 inch movement
300% for the 11.5 inch movement
Pattern C—100% for the 10 inch movement
100% for the 11.5 inch movement.

learning effect and included patterns which gave effective grouping, the data from the first six work spells were considered as preliminary and the data from Nos. 7, 8, and 9 formed the basis for the conclusions reached.

Results.—The data from work spells Nos. 7, 8, and 9 are given in Tables XIII, XIV, and XV.

All of the operators, except one, reported a feeling of grouping the work into cycles of three insertions starting with the hole preceding the five inch movement for work spell No. 7. The operator

TABLE XIII

NUMBER OF CYCLES MISSED BY EACH OPERATOR EACH MINUTE OF WORK SPELL NUMBER 7

Operators' Numbers	Minutes of Work Spell																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
1	0	0	0	0	1	2	0	0	2	0	1	0	4	0	2	2	0	1	1	1	3	2	3	1	2	1	1	1	0	0	31
2	0	0	1	0	0	0	0	1	2	0	3	0	1	3	0	1	0	0	0	0	0	0	2	2	1	0	0	0	0	0	17
3	0	1	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	1	0	0	2	0	0	1	1	1	1	1	12
4	0	0	0	0	1	0	0	0	0	1	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	6
5	1	3	3	2	2	2	5	2	2	1	1	1	3	2	3	2	3	2	1	4	5	2	5	3	3	1	3	3	1	0	71
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1	1	0	0	1	1	0	0	1	0	0	1	8
7	1	0	1	0	2	1	0	0	0	0	0	0	0	3	2	0	0	0	1	1	1	0	0	2	0	1	3	2	1	0	22
8	0	1	0	0	1	1	0	1	1	0	1	1	0	0	2	1	0	1	1	0	3	0	1	1	1	0	0	1	1	1	21
9	0	0	0	0	1	0	0	0	1	2	0	1	0	0	2	0	2	2	0	1	2	1	0	0	1	0	0	0	0	2	18
10	0	0	0	0	1	2	1	0	1	1	1	1	2	1	1	0	3	1	2	1	0	1	2	2	2	1	2	4	1	0	34

TABLE XIV

NUMBER OF CYCLES MISSED BY EACH OPERATOR EACH MINUTE OF WORK SPELL NUMBER 8

Operators' Numbers	Minutes of Work Spell																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
1	0	1	0	1	0	0	0	1	1	2	1	2	2	0	1	0	0	2	1	1	0	0	2	1	0	1	2	0	0	1	23
2	0	0	0	0	0	0	0	0	0	1	0	0	0	1	1	2	1	0	1	0	0	0	1	1	1	1	1	0	2	0	14
3	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	1	1	0	1	0	0	1	0	0	1	0	8
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
5	0	1	1	0	1	0	0	0	1	1	0	1	0	1	0	0	0	0	0	1	0	3	0	0	0	1	1	0	0	0	13
6	0	0	0	0	0	1	0	1	0	0	2	1	1	3	0	0	0	0	1	0	0	1	1	2	0	1	3	0	1	1	20
7	0	0	0	1	0	0	0	1	0	0	1	0	0	1	0	1	0	0	1	1	0	1	2	2	2	0	3	0	1	0	18
8	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	0	1	0	0	0	0	1	2	1	0	0	1	1	0	11
9	0	0	1	0	1	0	0	1	1	0	1	1	1	0	1	1	0	0	0	0	1	0	2	0	0	1	0	1	0	0	14
10	0	0	0	0	0	0	1	0	0	0	0	1	1	2	0	0	0	0	1	0	1	0	0	2	0	2	2	1	1	1	16

who did not report grouping took the admonition, "Let's see what you can do!", too seriously, and when he found that the feeling of grouping seemed to be annoying he used the leeway provided in the temporal pattern to smooth out the timing to make merely regular work.

All of the operators reported grouping for work spell No. 9 which was a repetition of the conditions of work spell No. 7.

In short, work spells No. 7 and No. 9 were employed in doing the task rhythmically.

TABLE XV

NUMBER OF CYCLES MISSED BY EACH OPERATOR EACH MINUTE OF WORK SPELL NUMBER 9

Operators' Numbers	Minutes of Work Spell																														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Total
1	3	0	1	2	1	0	1	0	0	1	1	0	0	1	2	2	1	0	0	1	0	0	0	2	3	0	2	2	2	2	30
2	0	1	1	1	0	2	0	3	1	0	0	0	1	1	0	2	0	0	0	1	2	0	1	3	1	0	0	1	0	1	23
3	0	1	0	0	1	1	1	0	0	2	1	0	0	2	0	1	0	1	1	2	0	1	1	1	2	2	1	0	1	2	25
4	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4
5	1	1	0	2	0	2	2	3	0	1	1	1	2	1	1	3	2	0	1	1	0	0	3	1	3	0	0	1	1	1	35
6	1	2	1	2	2	3	2	1	0	1	0	0	1	1	0	2	1	1	0	0	2	1	1	3	2	2	2	3	0	0	37
7	0	0	0	0	1	0	1	1	0	0	1	0	1	0	1	1	1	0	0	1	1	3	0	2	1	1	2	2	4	4	29
8	1	0	0	0	0	0	2	2	0	2	1	1	1	2	1	2	1	0	0	1	1	0	2	0	1	0	2	3	2	2	30
9	0	0	0	1	1	0	0	0	0	1	2	0	1	3	0	1	1	0	0	0	2	1	0	0	1	0	3	4	0	2	24
10	0	0	1	0	0	0	1	1	3	1	2	1	2	0	1	1	1	2	2	2	1	1	0	1	1	1	2	2	1	1	32

For work spell No. 8 none of the operators reported a feeling of grouping but reported a feeling of merely continuous, regular work.

These subjective impressions were received after the completion of all the work spells at which time the operators were first informed of the number of misses they had made during each work spell. (The complete verbal reports are given on page 54.)

Now it is true that the operators had worked twice previously at the arrangement presented in work spell No. 8, but on the other hand no further learning took place between work spell No. 7 and No. 9 as evidenced by the fact that the operators averaged more misses at the same arrangement in work spell No. 9 as compared to No. 7, as indicated in Table XVIII.

Furthermore, all the operators reacted in practically the same manner to the temporal patterns of work spells Nos. 7, 8, and 9,

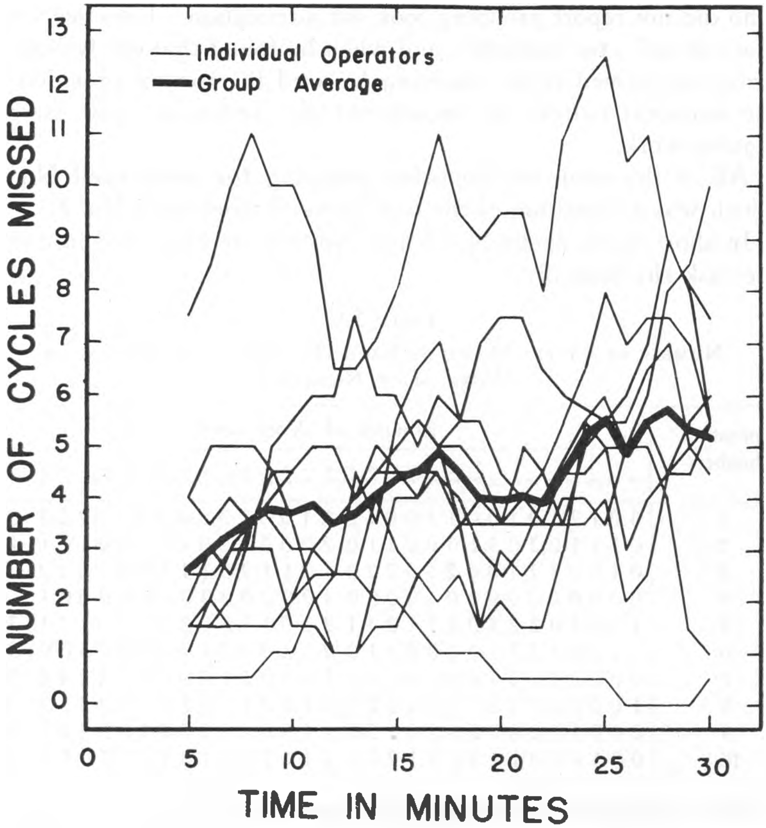

FIG. 22. Five minute moving totals of the number of cycles missed during rhythmical work. Five minute moving totals placed at last minute in total.

indicating that the difference in the order of presentation of the patterns of the first six work spells did not influence the results.

It seems certain that the operators had passed the critical point where learning ceases as far as their ability to insert the electrode into the holes as required by any temporal pattern was concerned, and that the data indicates the results of varying this pattern. Furthermore, one pattern was rhythmical in that it created a feeling of grouping. The other pattern did not and was merely regular. Also, the rhythmical cycle called for the three insertions in only 0.107 second less than the merely regular cycle which is a difference of 0.53 per cent less of the total cycle time, with this

Table XVI

Five Minute Moving Totals of the Number of Cycles Missed During Rhythmical Work

(Based on Averages of Work Spells Nos. 7 and 9)

(Five minute moving totals placed at last minute in total)

Minute of Work Spell	Operators' Numbers 1	2	3	4	5	6	7	8	9	10
5	4.0	2.0	1.5	0.5	7.5	4.0	2.5	1.5	1.5	1.0
6	3.5	3.0	2.0	0.5	8.5	5.0	2.5	1.5	1.5	2.0
7	4.0	2.5	1.5	0.5	10.0	5.0	3.0	2.0	1.5	3.0
8	3.5	3.5	1.5	0.5	11.0	5.0	3.0	3.5	1.5	3.0
9	3.5	4.5	1.5	1.0	10.0	4.0	3.0	4.0	1.5	5.0
10	3.0	4.5	2.0	1.0	10.0	3.5	1.5	4.5	2.0	5.5
11	3.0	5.0	2.5	2.0	9.0	2.0	1.5	5.0	3.0	6.0
12	2.5	5.0	2.5	2.5	6.5	1.0	1.0	5.0	3.5	6.0
13	4.5	4.0	2.5	2.5	6.5	1.0	1.0	4.0	4.0	7.5
14	3.5	4.5	4.0	2.0	7.0	1.5	2.5	4.5	5.0	6.0
15	5.5	4.5	3.0	2.0	8.0	1.5	4.0	5.0	4.5	6.0
16	6.5	4.5	2.5	1.5	9.5	2.5	4.0	5.5	4.0	5.0
17	7.0	4.5	2.0	1.0	11.0	3.0	4.5	5.0	5.0	6.0
18	5.5	3.5	2.5	1.0	9.5	3.5	4.0	5.0	5.5	5.5
19	5.5	1.5	1.5	1.0	9.0	3.5	3.0	4.5	4.0	7.0
20	4.5	2.0	3.0	0.5	9.5	3.5	2.5	3.5	3.5	7.5
21	4.0	1.5	2.5	0.5	9.5	3.5	3.0	4.0	5.0	7.5
22	4.5	1.5	3.0	0.5	8.0	3.5	4.0	3.5	4.5	6.5
23	5.5	3.0	4.0	0.5	11.0	3.5	4.0	4.5	3.5	6.0
24	6.5	5.5	4.0	0.5	12.0	5.0	5.5	4.5	3.5	5.5
25	8.0	6.0	3.5	0.5	12.5	5.5	5.0	5.0	4.0	5.5
26	7.0	5.0	5.0	0.0	10.5	5.5	5.0	3.0	2.0	6.0
27	7.5	5.0	5.5	0.0	11.0	6.5	6.0	4.0	2.5	7.0
28	7.5	4.0	4.5	0.0	9.0	7.0	8.0	4.5	4.5	9.0
29	7.0	1.5	5.0	0.0	8.0	5.0	8.5	5.5	4.5	8.5
30	5.5	1.0	5.5	0.5	5.5	4.5	10.0	6.0	5.5	7.5

extra time being dissipated in rest or in comparatively slow movement between cycles.

The number of cycles missed by each operator each minute of work spell No. 7 was added to the number of misses for each corresponding minute of work spell No. 9 and averaged. The five minute moving totals of the number of cycles missed, for each operator, based on these averages, are given in Table XVI. These are shown graphically with the group average five minute moving total of misses in Fig. 22.

The five minute moving totals of the number of cycles missed by

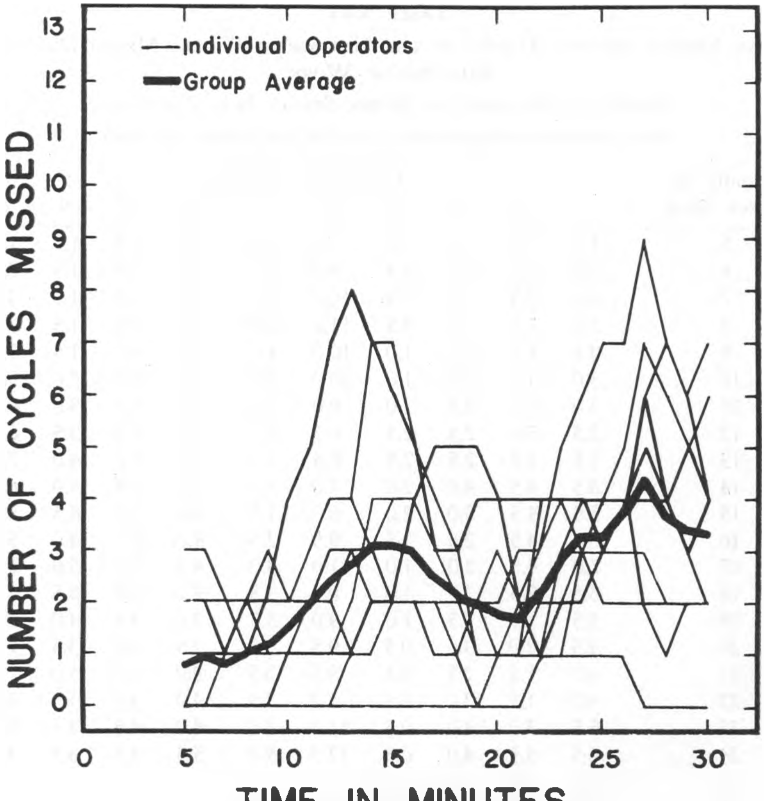

FIG. 23. Five minute moving totals of the number of cycles missed during merely regular work. Five minute moving totals placed at last minute in total.

each operator during work spell No. 8 are given in Table XVII. These are shown graphically with the group average five minute moving total of misses in Fig. 23.

The total number of cycles missed by each operator during work spells Nos. 7, 8, and 9, and the average of work spells Nos. 7 and 9 for each operator are given in Table XVIII.

The group average five minute moving totals of the number of cycles missed during rhythmical work (work spells Nos. 7 and 9 averaged) and during merely regular or non-rhythmical work (work spell No. 8) are given in Table XIX and are shown graphically in Fig. 24.

TABLE XVII

FIVE MINUTE MOVING TOTALS OF THE NUMBER OF CYCLES MISSED DURING MERELY REGULAR WORK

(WORK SPELL NO. 8)

(Five minute moving totals placed at last minute in total)

Minute of Work Spell	Operators' Numbers 1	2	3	4	5	6	7	8	9	10
5	2	0	0	0	3	0	1	0	2	0
6	2	0	0	0	3	1	1	0	2	0
7	1	0	0	0	2	1	1	0	2	1
8	2	0	0	0	1	2	2	0	2	1
9	2	0	0	0	2	2	1	1	3	1
10	4	1	0	0	2	2	1	2	2	1
11	5	1	0	0	2	3	2	2	3	1
12	7	1	0	0	3	4	2	2	4	1
13	8	1	1	0	3	4	1	3	4	2
14	7	2	1	0	3	7	2	2	3	4
15	6	2	2	0	2	7	2	2	4	4
16	5	4	2	0	2	5	2	2	4	4
17	3	5	2	0	1	4	2	2	3	3
18	3	5	1	0	1	3	2	2	2	2
19	4	5	2	0	0	1	2	2	2	1
20	4	4	2	0	1	1	3	1	1	1
21	4	2	3	0	1	1	2	1	1	2
22	4	1	3	1	4	2	3	1	1	2
23	4	2	4	1	4	3	5	1	3	2
24	4	2	3	1	4	4	6	3	3	3
25	3	3	2	1	3	4	7	4	3	3
26	4	4	2	1	4	5	7	4	3	4
27	6	5	2	0	2	7	9	4	3	6
28	4	4	1	0	2	6	7	4	2	7
29	3	5	2	0	2	5	6	3	2	6
30	4	4	2	0	2	6	4	2	2	7

Conclusions.—For the operators used in this experiment and for the work spells tested:

1. The operators did not prefer the rhythmical method to the merely regular but preferred the merely regular.
2. The rhythmical work was not less fatiguing since the group average five minute moving total of misses made during rhythmical work is just as much greater than the corresponding figure for the merely regular work at the end of the work spell as it was at the beginning and in addition,

both of these values vary in approximately the same fashion throughout the work spell.

3. A common complaint of the operators was that with the rhythmical work they had to "restart" themselves for each cycle while with the merely regular work they just worked

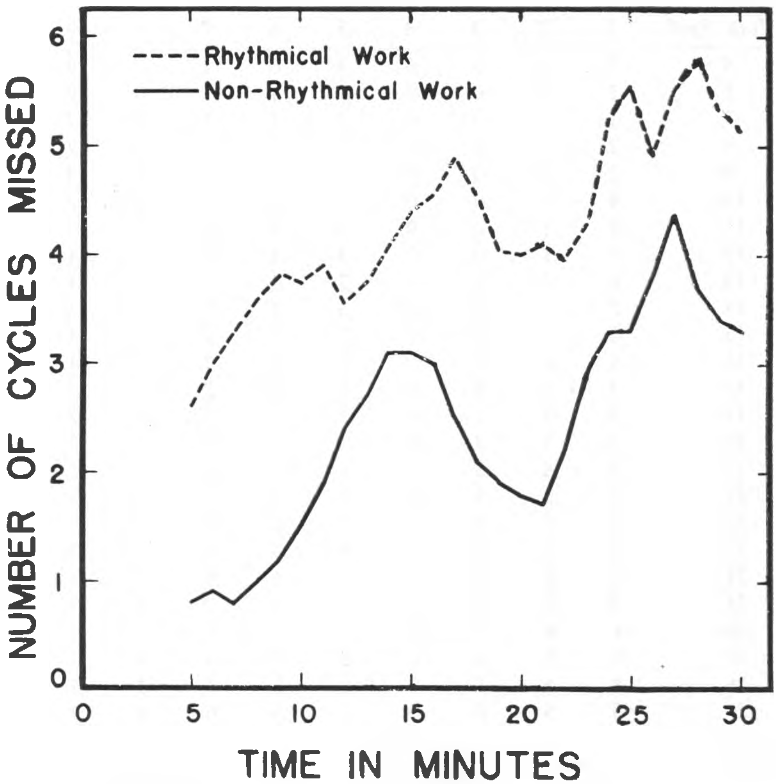

FIG. 24. Group average of five minute moving totals of the number of cycles missed during rhythmical and merely regular (non-rhythmical) work. Five minute moving totals placed at last minute in total.

"continuously" indicating that the merely regular work was more conducive to automaticity than the rhythmical.

4. All of the operators averaged a greater number of cycles missed during rhythmical work than during the merely regular work indicating that the rhythmical work was less efficient in that the workers completed fewer cycles in an equal period of time than they did with the merely regular work.

TABLE XVIII
TOTAL NUMBER OF CYCLES MISSED BY EACH OPERATOR DURING EACH WORK SPELL AND AVERAGE OF WORK SPELLS NOS. 7 AND 9

Work Spell	Operators' Numbers										
	1	2	3	4	5	6	7	8	9	10	Average
7	31	17	12	6	71	8*	22	21	18	34	24.0
8	23	14	8	1	13	20	18	11	14	16	13.8
9	30	23	25	4	35	37	29	30	24	32	26.9
$\frac{7+9}{2}$	30.5	20	18.5	5	53	22.5	25.5	25.5	21	33	25.4

*This is the work spell in which the operator used the leeway in the pattern to avoid grouping.

TABLE XIX
GROUP AVERAGE FIVE MINUTE MOVING TOTALS OF THE NUMBER OF CYCLES MISSED DURING RHYTHMICAL AND MERELY REGULAR WORK
(Five minute moving totals placed at last minute in total)

Minute of Work Spell	Rhythmical	Regular
5	2.60	0.8
6	3.00	0.9
7	3.30	0.8
8	3.60	1.0
9	3.80	1.2
10	3.75	1.5
11	3.90	1.9
12	3.55	2.4
13	3.75	2.7
14	4.10	3.1
15	4.40	3.1
16	4.55	3.0
17	4.90	2.5
18	4.55	2.1
19	4.05	1.9
20	4.00	1.8
21	4.10	1.7
22	3.95	2.2
23	4.55	2.9
24	5.26	3.3
25	5.55	3.3
26	4.90	3.8
27	5.50	4.4
28	5.80	3.7
29	5.35	3.4
30	5.15	3.3

Remarks of the Operators.—Remarks were solicited from the operators after the completion of the ninth work spell. Leading questions were avoided.

Operator 1.

This was more difficult than work spell eight. It makes groups of three holes but breaks the continuity of action. I have to accelerate at hole 1 to hole 2 and then almost stop at 1 again before inserting the peg. Very annoying.

Operator 2.

I did not like this as well as the last run (meaning work spell No. 8). I came down too fast on hole 2 probably due to having to restart myself each cycle.

Operator 3.

Good grouping from this into cycles of three holes. The last work spell gave me no feeling of grouping but was just continuous work. There did not feel as if there was more fatigue this time.

Operator 4.

Good grouping and breaking of work into cycles this way but requires slightly more concentration. I would prefer the merely regular.

Operator 5.

I felt excellent grouping on this work spell No. 9 but did not during No. 8. I have to concentrate to start each cycle with a new impulse on work spells Nos. 7 and 9.

Operator 6.

Good grouping on this but it requires closer attention (than work spell No. 8) while it appears not to. Gets very hard toward end.

Operator 7.

Good grouping which I liked, but you just can't hit them (the holes) at the end. You start the cycle too fast or too late. All in all, I would prefer the (merely regular) way of work spell No. 8.

Operator 8.

Good grouping but this seemed to spoil my aim. I would prefer last run (work spell No. 8). Last run gave me a feeling of continuity.

Operator 9.

Good grouping. Excellent. No grouping from arrangement of work spell No. 8. This makes cycles but other does not. I prefer the other.

Operator 10.

Good grouping but annoying as it breaks continuity of work and requires starting each cycle.

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Bulletin 3. Tests of Anchorages for Reinforcing Bars, by Chesley J. Posey, 1933. 32 pages, 18 figures, price $0.50.

Bulletin 4. The Physical and Anti-Knock Properties of Gasoline Blends, by Theodore R. Thoren, 1934. 32 pages, 13 figures, price $0.35.

Bulletin 5. The Transportation of Detritus by Flowing Water —I, by F. T. Mavis, Chitty Ho, and Yun-Cheng Tu, 1935. 56 pages, 15 figures, price $0.50.

Bulletin 6. An Investigation of Some Hand Motions Used in Factory Work, by Ralph M. Barnes, 1936. 60 pages, 22 figures, price $0.60.

Bulletin 7. A Study of the Permeability of Sand, by F. T. Mavis and Edward F. Wilsey, 1936. 32 pages, 12 figures, price $0.35.

Bulletin 8. Radiation Intensities and Heat-Transfer in Boiler Furnaces, by Huber O. Croft and C. F. Schmarje, 1936. 32 pages, 17 figures, price $0.35.

Bulletin 9. A Summary of Hydrologic Data, Ralston Creek Watershed, 1924–35, by F. T. Mavis and Edward Soucek, 1936. 72 pages, 25 figures, price $0.50.

Bulletin 11. The Transportation of Detritus by Flowing Water

Bulletin 10. Report on Hydraulics and Pneumatics of Plumbing Drainage Systems—I, by F. M. Dawson and A. A. Kalinske, 1937. 32 pages, 5 figures, price $0.35.
—II, by F. T. Mavis, Te-Yun Liu, and Edward Soucek, 1937. 32 pages, 8 figures, price $0.35.

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