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EFFECT OF LEVER SIZE UPON TIME
REQUIRED TO OPERATE

A Thesis

Submitted to the Faculty

of

Purdue University

by

Antonio Augusto Abreu Caminada

In Partial Fulfillment

of the

Requirements for the Degree

of

Master of Science

in

Industrial Engineering

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THE UNIVERSITY OF CHICAGO
DEPARTMENT OF CHEMISTRY
PHYSICAL CHEMISTRY
OF
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IN CONNECTION WITH THE
RESEARCH LABORATORY OF
PHYSICAL CHEMISTRY
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1911-1912

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ABSTRACT

This experiment deals with the determination of the effect of the size of a lever upon the time required to operate it.

The equipment was built to provide a constant torsional resistance which was to be overcome by an operator using a lever that moved between two mechanical stops.

A kymograph was used to register the time and provided an effective means to analyze the operator performance in regard to time used to operate, as well as to pace maintained and correct operation.

Ten subjects were used; they were college students and varied considerably in age and physical characteristics.

Twenty-five combinations of five levers of different sizes and five different torques were used. All the operators were instructed to operate the lever at the maximum possible speed that they thought they would be able to maintain during eight seconds.

The position of the operator relative to the equipment was kept constant and such that his elbow was 16.4 inches above the shaft around which the lever rotated (this length corresponds to the average lever size) and the forearm length away from it.

It was concluded that, under the conditions of the

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experiment and for the group of operators who performed the tests,

- (a) when the torque increases and the lever size is kept constant, the time required to operate increases closely proportional to the torque.
- (b) The time required to operate is closely proportional to the distance that the hand has to travel.
- (c) The path that the hand has to travel is, probably, the predominant factor determining the time for operation.
- (d) The 10-inch lever requires the minimum time for operation and the 25-inch lever requires the maximum time for operation.

INTRODUCTION AND PURPOSE

When one examines a modern machine tool, generally he is led to the conclusion that it has achieved a relatively high degree of perfection in regard to the performance of its mechanisms. However, if further consideration is given to the analysis of its adequacy in regard to its use by the human element, it is not always possible to arrive at a similar conclusion. Only by complete integration of machine and operator is it possible to get complete efficiency in machine tool operation.

One of the elements which contributes to efficient operation of machine tools is adequate controls. The determination of adequate controls for different situations which exist in practice is an important problem that has not been given much consideration. Therefore, in developing a machine the design engineer probably will find inadequate information to use in order to meet the needs of the required ease of operation.

The experiment which is described in this paper originated from the desire to give a small contribution to the advancement of the knowledge of the immense field of application of handwheels, cranks, levers and knobs.

The author chose levers as his problem and aimed to determine that lever size which requires the least time to operate when used to overcome a constant torsional resistance.

A SURVEY OF THE LITERATURE

The literature available dealing with research on the field of levers is not very extensive.

Barnes¹ discusses the subject of levers, crossbars and handwheels in regard to their position in machine tools and gives results of related studies.

Kühne² presents a discussion of studies dealing with determination of the effectiveness of levers, crossbars and handwheels under several different conditions.

Chapanis, Garner and Morgan³ present a general study, as well as a group of experimental results, of the subject of controls of airplanes. This study is primarily devoted to the analysis of control forces. These authors also discuss other kinds of controls, such as handwheels and cranks, as well as several types of movements which are of interest.

1. Barnes, R. M., "Principles of Motion Economy as Related to the Design of Tools and Equipment", Motion and Time Study, John Wiley and Sons, Inc., New York, 1951, Chap. 17.
2. Kühne, W. P., "Studies on the Optimum Force Exerted on Machine Controls", Industrielle Psychotechnik, June, 1927, Vol. III, No. 6, pp. 167-172.
3. Chapanis, A., Garner, W. R. and Morgan, C. T., "Controls for Human Use", How We Make Movements, Applied Experimental Psychology -- Human Factors in Engineering Design, John Wiley & Sons, Inc., New York, 1949, pp. 297-330; 264-297.

McFarland⁴ discusses results of studies of control forces related to the performance of the pilot of an airplane who operates sticks or wheels; he also analyzes the problem of maxima, minima and desirable forces.

Davis⁵ gives the results of research in the field of handwheels, cranks and crossbars and discusses related problems.

The existence of so limited information on the subject of lever operation seems to indicate the need for further study in this field and makes research dealing with it worthwhile to consider.

4. McFarland, R. A., Human Factors in Air Transport Design, McGraw-Hill Book Co., New York, 1948, pp. 384-388, 426-427, 478.
5. Davis, L. E., "Manual Controls", Machine Design, September, 1949, Vol. 21, pp.127-130.

Reference is made to the fact that the information on the
violations related to the operations of the plant is an
activity which operates within the plant and is not
the product of outside, third and fourth parties.

It is noted that the results of the investigation
of the plant, which are presented and discussed in the
report.

The existence of an illegal operation on the
subject of the investigation seems to indicate the need for
further study in this field and more extensive facilities
if possible to consider.

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EXPERIMENTAL PROCEDURE

While designing the experimental procedure, the author kept always in mind his intention of setting up the experiment in a way that resembled a practical situation and such that, if any useful results were obtained, they would represent an answer to a question which might arise in practice.

EQUIPMENT

The equipment was built to provide a means of applying a constant torsional resistance to a rotating shaft. This was to be turned at a certain angle (90°) with the use of a lever attached to one of its ends (Figure 1).

Several ways of getting a torque to be overcome by the action of a lever were considered, but they were ruled out as inadequate because they did not meet one of the most important requirements of the experiment, that is, to provide a constant torsional resistance. For this reason, the author decided to use a belt and drum arrangement (Figure 1). This provided a frictional torque which seemed to meet the requirement. Later, when the equipment was built and tested, this assumption was confirmed. The arrangement chosen not only allowed the torque to be kept constant but also permitted an easy change of torque for successive runs by simply varying the spring tension of each scale (Figure 1).



Figure 1

The Equipment used in the Experiment

The following table shows the results of the experiment. The data indicates that the system is highly effective in reducing the number of errors. The results are consistent across all trials and conditions.



The data shows a significant improvement in performance over time. The system's ability to learn from previous errors is a key factor in this improvement. The results are statistically significant and support the hypothesis that the system is effective.

Figure 1

Journal of Experimental Psychology

The choice of the range of torques to be used was based on two main considerations:

- (a) using torques usually found in practice;
- (b) the need of providing a reasonable variation among the torques in order to have a detectable difference in the related times.

In order to meet the first consideration, the author consulted different sources¹ and finally concluded that, in general, the torques found in practice are not excessive and that a maximum of 150 inch-pounds could be used. The difference among the torques was established as 30 inch-pounds. However, for convenience of use of the equipment, the following values were finally adopted: 28, 59, 89, 112 and 145 inch-pounds.

In choosing the lengths of levers to be used in the experiment, practical sources of information were also considered. The author examined the levers on the machine tools in the Michael Golden Laboratory of Purdue University; he also checked catalogues of tools². Since the sizes of levers found on both machine tools and hand tools range from 4 inches to about 45 inches (the majority being in the range of 10 to 25

1. Jergens Tool Specialty Co., Catalogue of Jigs and Fixtures Component Parts.
Siewek Tool Division of Domestic Industries, Inc., Clamps, Details and Fixtures Locks.
Chapanis, A., and others (Op. Cit.), pp. 320-321.
Davis, L. E. (Loc. Cit.).
Handbook of Human Engineering Data - Office of Naval Research - Technical Report SDC 199-1-1, Part VI, Chap. II, Sec. III.
2. Armstrong Bros. Tools Co., Armstrong Tools Catalogue;
Siewek Tool Div. of Domestic Industries, Inc. (Op. Cit.).

The results of the study are as follows:

(1) The study was conducted in the following manner:

(a) The study was conducted in the following manner:

(b) The study was conducted in the following manner:

The study was conducted in the following manner:

in the following manner:

In order to meet the study objectives, the study was conducted in the following manner:

for different reasons, and finally concluded that, in general,

the study found in practice the following results:

maximum of the study was 80%. The following

using the study was conducted in the following manner:

for convenience of use of the equipment, the following values

were finally adopted. 80, 85, 90, 95, 100, 105, 110, 115, 120, 125, 130, 135, 140, 145, 150.

It is assumed that the results of the study are as follows:

Experiment, practical courses of instruction were also conducted

test. The study concluded the following results:

The study found a maximum of 80% in the following manner:

maximum of 80%. The study was conducted in the following manner:

of the study was 80% and the following results were obtained:

which is shown in the following manner:

1. The study was conducted in the following manner:

2. The study was conducted in the following manner:

3. The study was conducted in the following manner:

4. The study was conducted in the following manner:

5. The study was conducted in the following manner:

6. The study was conducted in the following manner:

7. The study was conducted in the following manner:

inches), the following lengths were adopted: 10, 12, 15, 20 and 25 inches (Figure 2). The five levers used in the experiment were obtained by using an ordinary commercial type of ratchet wrench (Figure 2) and five extensions made of steel pipe. The use of the ratchet wrench was adopted to permit the use of a frictional torque without the inconveniences which would otherwise occur due to the periodic reversal of the motion of the lever during the test (this motion will be described in the Procedure). The inconveniences mentioned above refer to the slack of the belt and consequent change of the torque occurring during each reversal of the motion.

To measure the time involved in the operation, the kymograph¹ (Figure 1) was used. The time recorded was that required to move between two mechanical stops during several cycles. It was important that some means exist to check if the operator actually touched both stops with the lever; otherwise, the operation was incorrect and the time measured wrong. The pencil of the kymograph was actuated by a solenoid which was energized when the lever touched the stop and simultaneously closed a switch. The speed of the paper of the kymograph was equal to 9.031 inches per second.

1. For a description of the kymograph, see -- Barnes, R. M., "A Study of Hand Motion Using the Principle of the Kymograph", University of Iowa Studies in Engineering, Bulletin 6.

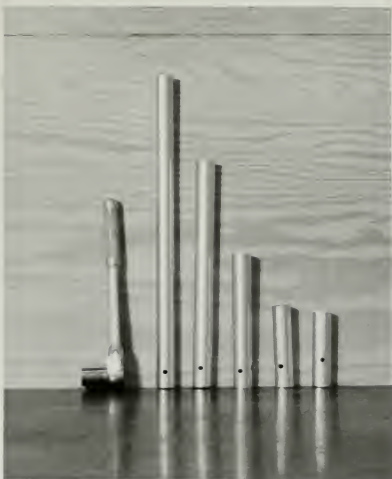


Figure 2

The Levers used in the Experiment



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PROCEDURE

Ten male college students were used as subjects. Their physical statistics are presented in Table 1.

The position of the operator relative to the equipment was given much consideration. In general, 36 inches is the height most commonly used for control devices on standard machine tools¹. Also, the performance of an operator facing equipment has been found much better than that obtained when he is at right angles to the equipment². In addition, it has been determined that motions involving mainly the elbow joint tend to give higher average velocities than those involving the shoulder joint, when the paths are similar³. Certainly, the ideal situation would have been to have the muscular pattern involved in each run exactly the same, by varying the position of the operator relative to the equipment. However, to do this would make the experiment much more involved. Weighing all these factors, a position was selected which was kept constant during all the runs for an operator. The position was such that the operator stood

1. Davis, L. E., (Op. Cit.).

2. Davis, L. E. (Ibid.)
Barnes, E. F., Mundel, E. E., "A Study of Motion Paths Involving Different Degrees of Change Direction", University of Iowa Studies in Engineering, Bulletin No. 12, p. 17.

3. University of Iowa Studies in Engineering (Ibid.).

EXPERIMENTAL

The following observations were made in the experiment.

1. The frequency of oscillation was measured in the range 1 to 100 Hz.

2. The amplitude of the oscillation was measured in the range 1 to 10 mm.

3. The period of the oscillation was measured in the range 1 to 100 ms.

4. The phase difference between the two oscillations was measured in the range 0 to 360 degrees.

5. The effect of the mass of the pendulum on the frequency of oscillation was studied.

6. The effect of the length of the pendulum on the frequency of oscillation was studied.

7. The effect of the amplitude of the oscillation on the frequency of oscillation was studied.

8. The effect of the phase difference on the frequency of oscillation was studied.

9. The effect of the mass of the pendulum on the amplitude of oscillation was studied.

10. The effect of the length of the pendulum on the amplitude of oscillation was studied.

11. The effect of the amplitude of the oscillation on the amplitude of oscillation was studied.

12. The effect of the phase difference on the amplitude of oscillation was studied.

13. The effect of the mass of the pendulum on the period of oscillation was studied.

14. The effect of the length of the pendulum on the period of oscillation was studied.

15. The effect of the amplitude of the oscillation on the period of oscillation was studied.

16. The effect of the phase difference on the period of oscillation was studied.

17. The effect of the mass of the pendulum on the phase difference was studied.

18. The effect of the length of the pendulum on the phase difference was studied.

19. The effect of the amplitude of the oscillation on the phase difference was studied.

20. The effect of the phase difference on the phase difference was studied.

21. The effect of the mass of the pendulum on the frequency of oscillation was studied.

22. The effect of the length of the pendulum on the frequency of oscillation was studied.

23. The effect of the amplitude of the oscillation on the frequency of oscillation was studied.

24. The effect of the phase difference on the frequency of oscillation was studied.

25. The effect of the mass of the pendulum on the amplitude of oscillation was studied.

26. The effect of the length of the pendulum on the amplitude of oscillation was studied.

27. The effect of the amplitude of the oscillation on the amplitude of oscillation was studied.

28. The effect of the phase difference on the amplitude of oscillation was studied.

Table 1

No.	PHYSICAL STATISTICS OF THE SUBJECTS				Full Arm Length (in)		
	(yr.)	(ft-in)	(lb)	Height (in)			
1	R. E. Doolittle	35	5' 11"	165	44	17	23.5
2	P. D. Viana	31	5' 7"	137	41	11	21
3	J. O. House	32	6' 2"	195	47	13	25
4	G. Kromp	31	5' 7"	170	40.5	10.5	21.5
5	O. Bromberg	22	5' 11"	175	45	11.5	24
6	G. A. Grabowsky	20	5' 11"	190	46	12	23
7	E. G. Lindquist	39	5' 10"	175	44	11	24
8	J. Crim	21	6' 1"	205	46	12	23
9	H. T. Fiechman	31	5' 11"	165	44	11	22.5
10	R. J. Wimmert	26	6' 0"	185	45	12	24

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
1900	10	15	20	25	30	35	40	45	50	55	60	65	600
1901	12	18	23	28	33	38	43	48	53	58	63	68	630
1902	11	16	21	26	31	36	41	46	51	56	61	66	610
1903	13	19	24	29	34	39	44	49	54	59	64	69	640
1904	14	20	25	30	35	40	45	50	55	60	65	70	670
1905	15	21	26	31	36	41	46	51	56	61	66	71	700
1906	16	22	27	32	37	42	47	52	57	62	67	72	730
1907	17	23	28	33	38	43	48	53	58	63	68	73	760
1908	18	24	29	34	39	44	49	54	59	64	69	74	790
1909	19	25	30	35	40	45	50	55	60	65	70	75	810
1910	20	26	31	36	41	46	51	56	61	66	71	76	840
1911	21	27	32	37	42	47	52	57	62	67	72	77	870
1912	22	28	33	38	43	48	53	58	63	68	73	78	900
1913	23	29	34	39	44	49	54	59	64	69	74	79	930
1914	24	30	35	40	45	50	55	60	65	70	75	80	960
1915	25	31	36	41	46	51	56	61	66	71	76	81	990
1916	26	32	37	42	47	52	57	62	67	72	77	82	1020
1917	27	33	38	43	48	53	58	63	68	73	78	83	1050
1918	28	34	39	44	49	54	59	64	69	74	79	84	1080
1919	29	35	40	45	50	55	60	65	70	75	80	85	1110
1920	30	36	41	46	51	56	61	66	71	76	81	86	1140

1920

in front of the equipment at a distance equal to his forearm length and having his elbow at a height of 16.4 inches (the average lever size) above the shaft. In this way, the variation of the muscular pattern was very slight and all operators had the same position relative to the equipment (platforms of different heights were used to meet this need).

During the test, the operator had to move the lever between two mechanical stops performing a certain number of cycles during 8 seconds (this time interval was determined in several trial runs and judged sufficient to give a reasonable number of cycles). The choice of this type of motion¹ was established because it seemed to give a constant performance.

Before the run, the operator was instructed on the operation of the equipment, but due to the simplicity of the operation, he did not perform any trial run. The operator was told to operate at the maximum speed that he thought possible to maintain for 8 seconds. He had to grasp the lever by its upper end and start the motion from the left-hand stop. He was given three signals: a "stand-by" signal before each run; a "start" signal; and a "stop" signal. The time was recorded from the instant in which the lever left the left-hand stop until the "stop" signal.

1. For a discussion of hand motions, see Mundel, M. E., "A Study of Rhythm in Hand Motions", Iowa Studies in Engineering, Bulletin No. 12, p. 55.

In front of the equipment of a laboratory used in the laboratory
 bench and having his hands at a distance of 20-25 inches from
 strongly (from him) were the results. In this way, the work-
 shop of the scientific research was very small and all exper-
 iments had the same position relative to the laboratory equip-
 ment of different persons were used in such a way.

During the year, the equipment had in use the same
 between the scientific group mentioned, a certain number of
 persons during 2 periods (this time intervals was determined in
 several trials and judged satisfactory to give a continuous
 amount of results). The number of this type of results was
 established because it seemed to give a constant performance.
 before the year, the research was conducted in the
 operation of the equipment, but due to the simplicity of the
 operation, it was not possible any trial was. The operation
 was held in groups at the beginning of the year in groups
 possible to obtain the 2 periods. In fact in front of
 laws of the group was not clear the action from the left-
 side group. It was given three elements: a "stand-by" class
 before each run, a "start" signal, and a "stop" signal. The
 time was recorded from the instant in which the laws were
 the individual step with the "start" signal.

1. For a description of the equipment, see page 10, p. 11.
 "A study of group in such conditions" was published in
 Psychological Bulletin vol. 42, p. 21.

Between runs a 3-minute rest pause was given. During that time the torque or the lever or both were changed following a randomized order of presentation (see Table 4, Appendix A). The purpose of the randomization was to decrease as much as possible the influence of that order upon the results (a table of random numbers was used to get the randomization¹).

Each operator performed twenty-five runs using five levers to overcome five torques each. At the end of the runs, none showed signs of fatigue or reported it when asked.

The operators had no knowledge of their output during the experiment; thus, the possible influence of this knowledge upon the muscular work was not present².

In getting the results of the tests, a consistent procedure was adopted to interpret the record of each run which had been obtained with the kymograph. Since several trial runs indicated that the operator reached his maximum speed, in most cases, after the second cycle and maintained this speed during five to seven cycles and then began to slow down again, it was decided to measure, in each run, five consecutive cycles beginning with the third cycle. Due to

1. Arkin, H., and Colton, R. R., Tables for Statisticians, Barnes and Noble, Inc., New York, Table 23.

2. Wagner, Charles W., "The Effect of Knowledge of Output on Muscular Work", Jour. of Experimental Psychology, Vol. XVIII, No. 1, 1935, pp. 80-90.

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the behavior of the ratchet lever, the cycle of operation consisted of two parts: during one part, the operator had to move the lever against the opposition of the frictional torque; during the other, the torque did not affect the operation, that is, the operator had practically no load to overcome. Only the loaded parts of the cycles were taken into consideration in the analysis of the results.

A scale of $\frac{1}{50}$ of one inch was used to measure the distance between two jogs in the kymograph record (Figure 3). This distance was proportional to the time spent by the operator to perform a semi-cycle; therefore, it was not necessary to convert the result into time. Also, the absolute values of the intervals of times themselves were unimportant, since the main concern was their relative values. Thus, only to plot the curves in Figures 4 and 5 were time values used. In all other cases, the distances obtained with the record given by the kymograph were used.

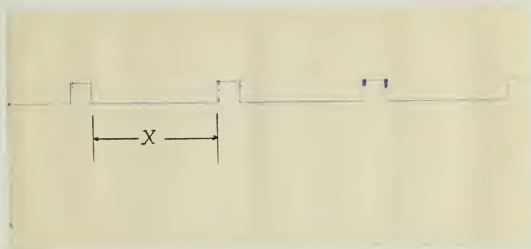


Figure 3

Sample of tape from Kymograph

RESULTS

The results for each combination of torque and lever are summarized and shown in Table 2.

Table 2

Average Lengths of Five Semi-Cycles for Each Combination of Torque and Lever

<u>Lever</u>	<u>Torque, In.-Lb.</u>				
	<u>28</u>	<u>59</u>	<u>89</u>	<u>112</u>	<u>145</u>
10	270.6	283.9	297.2	322.8	361.0
12	291.9	306.6	314.8	331.5	346.5
15	313.9	332.7	347.7	360.3	373.8
20	397.0	412.0	421.6	430.3	461.8
25	480.9	495.2	507.3	534.5	567.2

All numbers represent multiples of $\frac{1}{50}$ of one inch. As shown in Table 2, the 10-inch lever required the least time for all torques except 145 inch-pounds¹; whereas, the 25-inch lever required the maximum time for all torques.

Table 5 (Appendix B) presents the results by operators for each combination of levers and torques. The analysis of variance was used to examine the data. The principal steps of this procedure are shown in Appendix C.

1. However, in Appendix D, it is shown that the minimum found with the 12-inch lever is not significant.

The results for each condition of testing are given in Table 3. The results are given in Table 3.

Table 3

The results for each condition of testing are given in Table 3. The results are given in Table 3.

Table 3

Condition	10	20	30	40	50
10	0.100	0.100	0.100	0.100	0.100
20	0.100	0.100	0.100	0.100	0.100
30	0.100	0.100	0.100	0.100	0.100
40	0.100	0.100	0.100	0.100	0.100
50	0.100	0.100	0.100	0.100	0.100

All numbers represent percentages of the total. As shown in Table 3, the 10-100 test yielded the least error for all subjects except for one subject, whose error was 100%.

Table 3 (continued) shows the results of the experiment for each condition of testing and subject. The analysis of variance was used to compare the data. The statistical results of this experiment are given in Appendix 3.

I, however, in Appendix 3, it is shown that the results for the 10-100 test are not significant.

Two groups of curves were plotted using the data summarized in Table 3. Also, the best fitting curve was determined in each case by means of the method of least squares (see Appendix D).

Figure 4 shows the curves (both fitted and experimental) for

$$t = f(l) \quad \text{for } T = \text{constant}$$

Figure 5 shows the curves (both fitted and experimental) for

$$t = F(T) \quad \text{for } l = \text{constant}$$

where t = time required to perform five semi-cycles

l = length of the lever

T = torque

In order to use time values on the curves, the following was done:

The values in Table 2 were divided by 451.55, that is, by the speed of the kymograph paper expressed in fiftieths of one inch per second. Table 3 presents the values obtained which were used in the experimental curves.

The purpose of this investigation is to determine the effect of the various factors mentioned above on the rate of reaction. The results are given in Table I. It is seen that the rate of reaction is increased by the presence of the catalyst and is decreased by the presence of the inhibitor.

The effect of the concentration of the reactants on the rate of reaction is shown in Table II.

The effect of the temperature on the rate of reaction is shown in Table III.

TABLE I
Effect of Catalyst and Inhibitor on the Rate of Reaction

TABLE II
Effect of Concentration of Reactants on the Rate of Reaction

TABLE III
Effect of Temperature on the Rate of Reaction

TABLE IV
Effect of Solvent on the Rate of Reaction

TABLE V
Effect of Pressure on the Rate of Reaction

TABLE VI
Effect of Light on the Rate of Reaction

TABLE VII
Effect of Time on the Rate of Reaction

TABLE VIII
Effect of Surface Area on the Rate of Reaction

TABLE IX
Effect of Stirring on the Rate of Reaction

TABLE X
Effect of Catalyst Concentration on the Rate of Reaction

TABLE XI
Effect of Inhibitor Concentration on the Rate of Reaction

TABLE XII
Effect of Reactant Concentration on the Rate of Reaction

TABLE XIII
Effect of Temperature on the Rate of Reaction

TABLE XIV
Effect of Solvent on the Rate of Reaction

TABLE XV
Effect of Pressure on the Rate of Reaction

TABLE XVI
Effect of Light on the Rate of Reaction

TABLE XVII
Effect of Time on the Rate of Reaction

TABLE XVIII
Effect of Surface Area on the Rate of Reaction

TABLE XIX
Effect of Stirring on the Rate of Reaction

TABLE XX
Effect of Catalyst Concentration on the Rate of Reaction

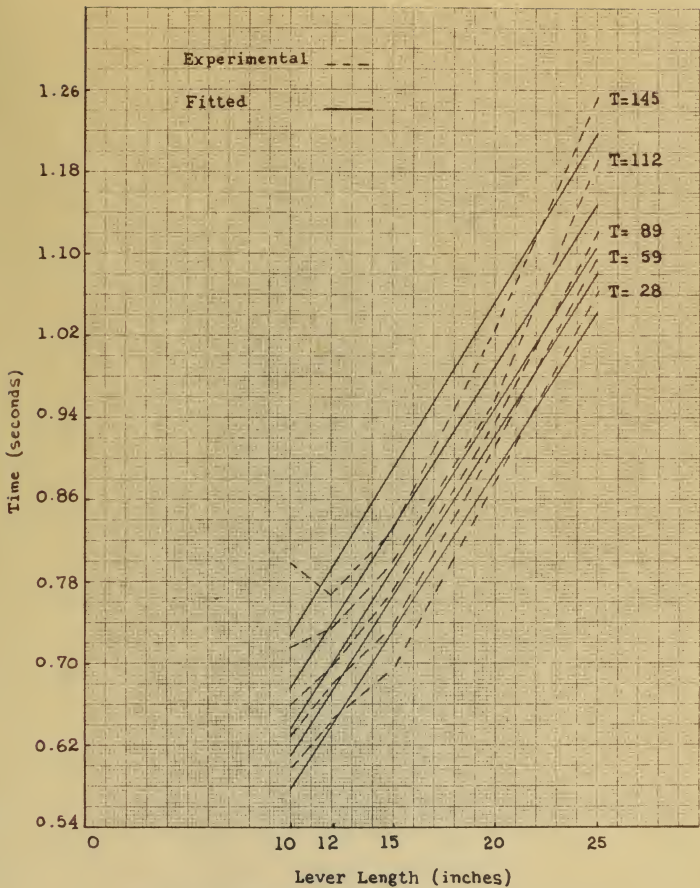


Fig. 4 - Curves for $t = f(l)$ for $T = \text{constant}$

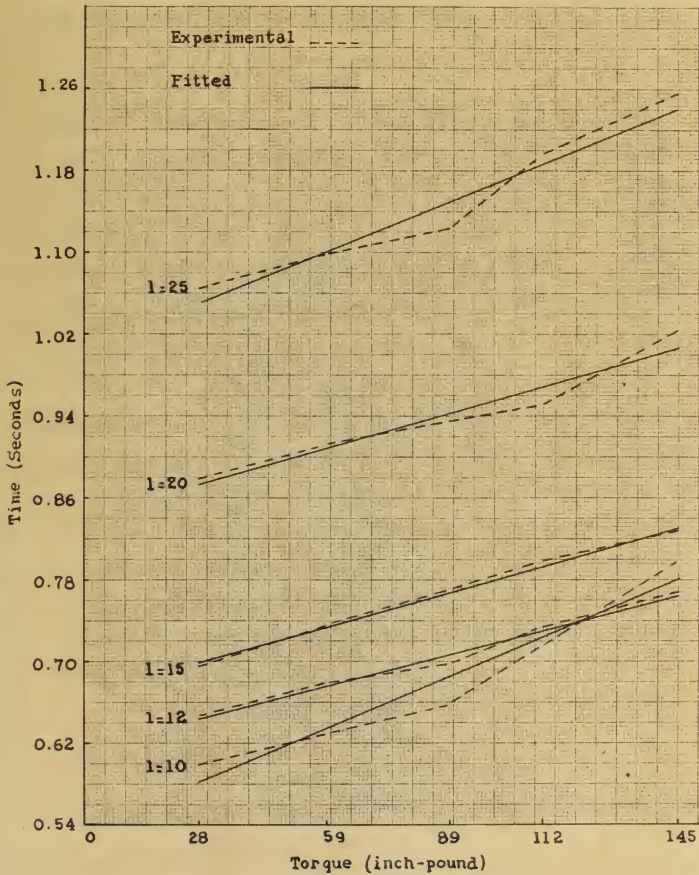


Fig. 5 — Curves for $t = F(T)$ for $1 = \text{constant}$

Table 3

Average duration, in seconds, of five semi-cycles
for each combination of torque and lever.

<u>Lever</u>	<u>Torque</u>				
	<u>28</u>	<u>59</u>	<u>89</u>	<u>112</u>	<u>145</u>
10	0.599	0.629	0.653	0.715	0.799
12	0.646	0.679	0.697	0.734	0.767
15	0.695	0.736	0.770	0.798	0.828
20	0.879	0.912	0.934	0.953	1.023
25	1.065	1.097	1.123	1.194	1.256

TABLE 2

For each individual in the sample, the following information is given: the number of times the individual was observed, the number of times the individual was observed in a particular state, and the number of times the individual was observed in a particular state and in a particular state.

State	Number of times observed	Number of times observed in a particular state			Total
		State 1	State 2	State 3	
1	10	5	3	2	10
2	15	8	4	3	15
3	12	6	5	1	12
4	8	4	3	1	8
5	10	5	4	1	10

DISCUSSION OF RESULTS

As mentioned before, the data were analyzed statistically by using an analysis of variance procedure. The results of this analysis are summarized in Table 6 of Appendix B.

The variance for torques, levers and individuals, respectively, Q_T , Q_l and Q_i , came out strongly significant. In Figures 4 and 5 we can easily detect the apparent influence of the variation among torques and levers.

The so-called interactions, that is, Q_{Tl} , Q_{Ti} and Q_{Til} , though still significant, are in much less degree and thus reveal a much less marked influence. Among these interactions, that concerned with levers versus individuals is the most highly significant. This indicates that, at least for this group of operators and set of levers, the variation of lever size affected the operation in different ways, though the results as a whole show a common and general trend. The interaction concerning torques versus individuals versus levers shows the least degree of significance and thus helps explain the kind of general result found, that is, a reasonable agreement among performances.

Let us examine now the curves of Figure 4. They are the lines

$$t = f(l) \quad \text{for } T = \text{constant}$$

Since the straight lines were the best fitting curves, we see

DECLARATION OF INTEREST

I, the undersigned, do hereby certify that the foregoing is a true and correct copy of the original as the same appears in the files of the Department of the Interior, and that I have no interest in the same.

Witness my hand and seal at Washington, D.C., this 1st day of January, 1901.

Very truly yours,
[Signature]

Notary Public for the District of Columbia

Subscribed and sworn to before me this 1st day of January, 1901.

Notary Public for the District of Columbia

Witness my hand and seal at Washington, D.C., this 1st day of January, 1901.

that there was a close proportionality among the lengths of the levers and the times required to operate. Because of the proportionality which exists between the lever size and the path that the hand of the operator had to follow, the previous statement amounts to saying that the time required to operate the lever was strongly dependent on the path that the hand followed. Probably, this was the dominant factor affecting the time.

The fitted curves show that the 10-inch lever required the least time to operate under all torques; however, no conclusion can be drawn for sizes smaller than 10 inches.

Let us examine now the curves of Figure 5. They are the lines

$$t = F(T) \quad \text{for } l = \text{constant}$$

Since straight lines were the best fitting curves, it is apparent that there is close proportionality among the times and the torques.

that there was a slight irregularity about the position
of the leaves and the lines seemed to be slightly
of the proportionally which were between the leaves and
and the lines had the same of the number but no follow,

the previous statement seemed to imply that the lines
required to appear the leaves was through experiment on the
with that the same followed. Possibly this was the dis-
posed factor affecting the lines.

The first curve was that the 10-inch leaves were
given the lines to appear with the leaves however,
no conclusion was to be drawn for lines within the 10 leaves.
but as a matter of fact the curve of lines is very

the lines

the lines

the lines were the best fitting curve, as is
shown in the diagram. It is clear that the lines
and the leaves.

the lines

the lines

the lines

the lines

the lines

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the lines

the lines

the lines

CONCLUSIONS

Under the conditions of the experiment and for the group of operators who performed the tests, the following conclusions may be drawn:

- (a) When the torque increases and the lever size is kept constant, the time required to operate increases closely proportional to the torque.
- (b) The time required to operate is closely proportional to the distance that the hand has to travel.
- (c) The path that the hand has to travel is, probably, the predominant factor determining the time for operation.
- (d) The 10-inch lever requires the minimum time for operation and the 25-inch lever requires the maximum time for operation.

CONFIDENTIAL

Under the conditions of the agreement, the
 the terms of agreement are specified in Part I, and the
 terms of agreement may be stated:

- (a) When the parties involved and the terms are in part
 constant, the law applies to the parties concerned
 already mentioned in the report.
- (b) The law applied to parties is already mentioned
 to the extent that the law has no effect.
- (c) The law that the law has no effect is, especially, the
 provisions of the law concerning the law of operation.
- (d) The law that the law applies the law that the law
 that the law that the law applies the law that the law
 the operation.

APPENDIX A

Tables 4a to 4j-- Order of Presentation

These tables present the randomized order of presentation for each subject.

The conventions used in Table 5 (Appendix B) were also adopted here.

4a -- Subject No. 1

Lever No.	Run No.									
						Torque No.				
5	1	1	2	5	3	4	4	3	5	2
2	6	3	7	1	8	5	9	2	10	4
3	11	2	12	3	13	5	14	4	15	1
4	16	4	17	2	18	3	19	5	20	1
1	21	3	22	4	23	5	24	1	25	2

APPENDIX A

Table A-1 -- List of Experiments

The table presents the numbered names of experiments for each subject.

The numbers are listed in Table B (Appendix B) and also listed here.

Table A-1 -- List of Experiments

Level No.	List of Experiments					
	1	2	3	4	5	6
1	11	12	13	14	15	16
2	17	18	19	20	21	22
3	23	24	25	26	27	28
4	29	30	31	32	33	34
5	35	36	37	38	39	40

4b - Subject No. 2

Lever No.	Run No.				Torque No.					
2	26	5	27	3	28	1	29	4	30	2
1	31	4	32	5	33	1	34	3	35	2
3	36	2	37	3	38	5	39	4	40	1
4	41	3	42	1	43	4	44	2	45	5
5	46	1	47	4	48	5	49	2	50	3

4c - Subject No. 3

Lever No.	Run No.				Torque No.					
3	51	1	52	5	53	4	54	5	55	2
5	56	3	57	4	58	2	59	5	60	1
1	61	5	62	1	63	3	64	2	65	4
2	66	2	67	4	68	5	69	1	70	3
4	71	4	72	1	73	5	74	3	75	2

4d - Subject No. 4

Lever No.	Run No.				Torque No.					
2	76	2	77	4	78	1	79	5	80	3
3	81	4	82	1	83	5	84	3	85	2
5	86	5	87	2	88	1	89	3	90	4
4	91	3	92	1	93	4	94	2	95	5
1	96	1	97	5	98	2	99	4	100	3

Table 1 - 1950

Year	1950	1951	1952	1953	1954	1955
1	10	10	10	10	10	10
2	10	10	10	10	10	10
3	10	10	10	10	10	10
4	10	10	10	10	10	10
5	10	10	10	10	10	10

Table 2 - 1950

Year	1950	1951	1952	1953	1954	1955
1	10	10	10	10	10	10
2	10	10	10	10	10	10
3	10	10	10	10	10	10
4	10	10	10	10	10	10
5	10	10	10	10	10	10

Table 3 - 1950

Year	1950	1951	1952	1953	1954	1955
1	10	10	10	10	10	10
2	10	10	10	10	10	10
3	10	10	10	10	10	10
4	10	10	10	10	10	10
5	10	10	10	10	10	10

4e - Subject No. 5

Lever No.	Run No.					Torque No.				
	101	102	103	104	105	106	107	108	109	110
5	4	5	2	1	3					
4	5	1	3	4	2					
3	3	5	4	2	1					
2	2	5	1	3	4					
1	1	5	3	2	4					

4f - Subject No. 6

Lever No.	Run No.					Torque No.				
	126	127	128	129	130	131	132	133	134	135
4	4	2	5	1	3					
3	5	2	4	3	1					
1	3	4	5	1	2					
2	2	3	5	4	1					
5	1	4	5	2	3					

4g - Subject No. 7

Lever No.	Run No.					Torque No.				
	151	152	153	154	155	156	157	158	159	160
1	5	2	3	4	1					
4	2	4	1	5	5					
5	4	2	3	5	1					
2	3	2	1	5	4					
3	1	5	2	4	3					

Table 1 - 1980

Year 1980					Total
101	102	103	104	105	5
106	107	108	109	110	5
111	112	113	114	115	5
116	117	118	119	120	5
121	122	123	124	125	5

Table 2 - 1981

Year 1981					Total
131	132	133	134	135	5
136	137	138	139	140	5
141	142	143	144	145	5
146	147	148	149	150	5
151	152	153	154	155	5

Table 3 - 1982

Year 1982					Total
161	162	163	164	165	5
166	167	168	169	170	5
171	172	173	174	175	5
176	177	178	179	180	5
181	182	183	184	185	5

4h - Subject No. 8

Lever No.	Run No.					Torque No.				
	176		177		178		179		180	
1	2	3	1	4	5	2	3	4	5	1
5	4	3	3	5	1	4	5	1	2	3
4	3	4	1	2	5	3	4	5	1	2
2	5	3	1	2	4	3	4	5	1	2
3	1	4	5	2	3	1	2	3	4	5

4i - Subject No. 9

Lever No.	Run No.					Torque No.				
	201		202		203		204		205	
3	2	3	1	4	5	2	3	4	5	1
5	5	4	1	3	2	5	4	3	2	1
4	1	3	5	2	4	1	2	3	4	5
1	3	5	4	2	1	3	4	5	1	2
2	4	2	5	1	3	4	5	1	2	3

4j - Subject No. 10

Lever No.	Run No.					Torque No.				
	226		227		228		229		230	
4	3	2	5	4	1	3	4	5	1	2
2	4	3	2	1	5	4	3	2	1	5
3	2	3	1	4	5	3	4	5	1	2
1	5	2	1	3	4	5	1	2	3	4
5	1	4	5	2	3	4	5	1	2	3

Table 10 - 1950

1950					1950
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100

Table 10 - 1951

1951					1951
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100

Table 10 - 1952

1952					1952
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100
100	100	100	100	100	100

APPENDIX B

Tables 5a to 5j -- Results by Operators

These tables present the results obtained for each operator and each combination of torques and levers, in the five measured semi-cycles. They also give the totals of these five semi-cycles. The numbers express fiftieths of one inch. The following convention was adopted to write the tables:

<u>Lever No.</u>	<u>Length</u>	<u>Torque No.</u>	<u>Value</u>
I	10	1	28
II	12	2	59
III	15	3	89
IV	20	4	112
V	25	5	145

TABLE 1. -- RESULTS OF ANALYSIS

The following analysis was made to determine the relative amounts of the various components in the samples. The results are given in the following table. The samples were analyzed by the method described in the report of the author, and the results are given in the following table.

Sample No.	Component	Amount	Percentage
1	1	10	10
2	2	15	15
3	3	10	10
4	4	10	10
5	5	10	10
6	6	10	10

TABLE 1. -- RESULTS OF ANALYSIS

Sample No.	Component	Amount	Percentage
7	7	10	10
8	8	10	10
9	9	10	10
10	10	10	10
11	11	10	10
12	12	10	10
13	13	10	10
14	14	10	10
15	15	10	10
16	16	10	10
17	17	10	10
18	18	10	10
19	19	10	10
20	20	10	10

Table 5a

Subject No. 1

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>Σ X</u>
I	1	49	48	43	45	41	226
	2	44	52	46	49	45	236
	3	48	49	41	49	49	236
	4	50	53	48	43	45	239
	5	69	72	64	63	65	333
II	1	51	53	52	52	51	259
	2	55	56	52	52	56	271
	3	53	57	53	56	59	278
	4	55	61	63	55	57	291
	5	58	60	57	59	59	291
III	1	57	55	57	52	55	276
	2	52	59	57	56	55	279
	3	65	58	56	53	55	287
	4	64	63	67	61	67	322
	5	79	69	68	67	67	350
IV	1	64	62	59	65	63	313
	2	64	65	62	65	70	326
	3	65	60	68	63	68	326
	4	60	60	69	73	65	327
	5	67	63	66	66	64	328
V	1	88	81	87	86	87	429
	2	84	85	88	85	91	433
	3	95	92	84	102	101	474
	4	93	98	100	98	102	491
	5	97	127	93	99	120	538

Table 10

1. on 1940

17	1	2	3	4	5	6	7
865	53	53	53	53	53	53	I
866	54	54	54	54	54	54	I
867	55	55	55	55	55	55	I
868	56	56	56	56	56	56	I
869	57	57	57	57	57	57	II
870	58	58	58	58	58	58	II
871	59	59	59	59	59	59	II
872	60	60	60	60	60	60	II
873	61	61	61	61	61	61	II
874	62	62	62	62	62	62	III
875	63	63	63	63	63	63	III
876	64	64	64	64	64	64	III
877	65	65	65	65	65	65	III
878	66	66	66	66	66	66	III
879	67	67	67	67	67	67	IV
880	68	68	68	68	68	68	IV
881	69	69	69	69	69	69	IV
882	70	70	70	70	70	70	IV
883	71	71	71	71	71	71	IV
884	72	72	72	72	72	72	V
885	73	73	73	73	73	73	V
886	74	74	74	74	74	74	V
887	75	75	75	75	75	75	V
888	76	76	76	76	76	76	V
889	77	77	77	77	77	77	V
890	78	78	78	78	78	78	V

Table 5b

Subject No. 2

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>ΣX</u>
I	1	62	69	61	63	68	323
	2	60	69	69	62	65	325
	3	69	78	78	75	69	369
	4	85	83	74	89	82	413
	5	84	84	92	86	88	434
II	1	73	87	72	76	72	360
	2	73	73	73	74	75	368
	3	85	78	76	73	73	385
	4	76	85	83	79	80	403
	5	98	79	90	83	80	430
III	1	71	69	75	69	79	363
	2	83	82	77	81	84	407
	3	84	92	84	80	84	424
	4	85	84	79	89	88	425
	5	96	98	95	90	83	462
IV	1	96	98	95	95	96	480
	2	103	103	101	95	95	497
	3	96	101	104	130	98	529
	4	106	103	107	105	110	531
	5	109	112	107	123	116	567
V	1	115	121	116	120	109	581
	2	121	115	118	115	111	580
	3	119	119	123	123	131	615
	4	130	123	129	134	117	633
	5	144	141	138	131	130	684

TABLE

ANALYSIS

No.	ANALYSIS					Amount	Total
	1st	2nd	3rd	4th	5th		
100	50	50	50	50	50	1	I
101	51	50	51	51	50	1	
102	50	50	50	50	50	2	
103	51	50	50	50	50	4	
104	50	50	50	50	50	2	
105	50	50	50	50	50	1	II
106	50	50	50	50	50	2	
107	50	50	50	50	50	2	
108	50	50	50	50	50	4	
109	50	50	50	50	50	2	
110	50	50	50	50	50	1	III
111	50	50	50	50	50	2	
112	50	50	50	50	50	2	
113	50	50	50	50	50	2	
114	50	50	50	50	50	2	
115	50	50	50	50	50	2	VI
116	50	50	50	50	50	2	
117	50	50	50	50	50	2	
118	50	50	50	50	50	2	
119	50	50	50	50	50	2	
120	50	50	50	50	50	2	V
121	50	50	50	50	50	2	
122	50	50	50	50	50	2	
123	50	50	50	50	50	2	
124	50	50	50	50	50	2	
125	50	50	50	50	50	2	

Table 5c

Subject No. 3

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>ΣX</u>
I	1	49	46	50	45	49	239
	2	53	51	53	50	54	261
	3	54	53	52	52	59	270
	4	53	58	58	54	58	281
	5	65	61	60	53	58	297
II	1	54	55	52	52	49	262
	2	60	56	56	57	53	282
	3	53	56	56	54	58	277
	4	53	56	60	56	60	285
	5	57	57	56	52	57	279
III	1	54	54	52	55	53	268
	2	53	55	58	56	52	274
	3	57	57	60	57	56	287
	4	60	62	62	62	65	311
	5	65	69	68	65	68	335
IV	1	74	72	70	72	68	356
	2	78	69	78	81	80	386
	3	76	81	79	72	76	384
	4	68	76	79	83	78	384
	5	85	84	92	100	84	445
V	1	90	88	85	84	88	435
	2	84	91	91	86	91	443
	3	84	95	88	87	92	446
	4	99	87	90	89	94	459
	5	89	93	120	92	100	494

Table 10

U. S. dollars

Year	1910	1911	1912	1913	1914	1915	Period
1910	100	100	100	100	100	100	I
1911	100	100	100	100	100	100	
1912	100	100	100	100	100	100	
1913	100	100	100	100	100	100	
1914	100	100	100	100	100	100	II
1915	100	100	100	100	100	100	
1916	100	100	100	100	100	100	
1917	100	100	100	100	100	100	
1918	100	100	100	100	100	100	III
1919	100	100	100	100	100	100	
1920	100	100	100	100	100	100	
1921	100	100	100	100	100	100	
1922	100	100	100	100	100	100	IV
1923	100	100	100	100	100	100	
1924	100	100	100	100	100	100	
1925	100	100	100	100	100	100	
1926	100	100	100	100	100	100	V
1927	100	100	100	100	100	100	
1928	100	100	100	100	100	100	
1929	100	100	100	100	100	100	

Table 5d

Subject No. 4

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>ΣX</u>
I	1	59	51	53	53	56	272
	2	53	57	53	60	61	284
	3	60	57	61	58	61	297
	4	62	63	61	57	65	308
	5	68	65	64	64	72	333
II	1	58	53	59	56	58	284
	2	59	60	60	62	61	302
	3	64	61	61	63	55	304
	4	63	64	63	68	63	321
	5	65	60	64	67	65	321
III	1	57	57	54	57	61	286
	2	60	62	53	56	59	290
	3	63	65	62	63	60	313
	4	63	61	64	64	70	322
	5	76	65	68	70	68	347
IV	1	81	77	80	78	77	393
	2	83	80	76	78	82	399
	3	81	85	75	86	81	408
	4	90	83	81	78	88	420
	5	92	100	79	88	85	444
V	1	104	95	100	93	91	488
	2	100	96	99	104	104	503
	3	97	108	100	107	105	517
	4	100	112	106	104	108	530
	5	115	107	101	107	113	543

Table 5eSubject No. 5

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>Σ X</u>
I	1	49	41	43	44	44	221
	2	45	43	48	39	43	223
	3	46	46	49	47	47	235
	4	53	53	53	53	43	255
	5	65	64	64	55	55	303
II	1	43	54	49	47	46	244
	2	43	52	45	49	54	248
	3	52	52	53	54	50	261
	4	57	53	60	56	53	279
	5	64	60	60	52	55	291
III	1	52	54	54	55	51	266
	2	57	54	53	53	56	273
	3	52	59	60	60	60	291
	4	70	59	58	61	60	308
	5	64	62	61	60	61	308
IV	1	54	63	63	74	74	326
	2	67	64	68	67	66	332
	3	73	68	64	66	68	341
	4	71	73	68	67	67	346
	5	82	91	82	79	81	415
V	1	83	84	90	79	77	413
	2	96	99	99	92	95	481
	3	98	83	97	116	98	492
	4	100	98	101	127	87	513
	5	142	99	100	99	97	537

TABLE 2

S. J. J. J. J. J.

Year	1911	1912	1913	1914	1915	1916	1917
1911	24	44	54	54	55	1	I
1912	24	55	55	56	56	2	
1913	25	71	55	55	55	3	
1914	25	55	55	55	55	4	
1915	25	55	55	55	55	5	
1916	25	55	55	55	55	6	
1917	25	55	55	55	55	7	
1918	25	55	55	55	55	8	
1919	25	55	55	55	55	9	
1920	25	55	55	55	55	10	
1921	25	55	55	55	55	11	
1922	25	55	55	55	55	12	
1923	25	55	55	55	55	13	
1924	25	55	55	55	55	14	
1925	25	55	55	55	55	15	
1926	25	55	55	55	55	16	
1927	25	55	55	55	55	17	
1928	25	55	55	55	55	18	
1929	25	55	55	55	55	19	
1930	25	55	55	55	55	20	
1931	25	55	55	55	55	21	
1932	25	55	55	55	55	22	
1933	25	55	55	55	55	23	
1934	25	55	55	55	55	24	
1935	25	55	55	55	55	25	
1936	25	55	55	55	55	26	
1937	25	55	55	55	55	27	
1938	25	55	55	55	55	28	
1939	25	55	55	55	55	29	
1940	25	55	55	55	55	30	
1941	25	55	55	55	55	31	
1942	25	55	55	55	55	32	
1943	25	55	55	55	55	33	
1944	25	55	55	55	55	34	
1945	25	55	55	55	55	35	
1946	25	55	55	55	55	36	
1947	25	55	55	55	55	37	
1948	25	55	55	55	55	38	
1949	25	55	55	55	55	39	
1950	25	55	55	55	55	40	
1951	25	55	55	55	55	41	
1952	25	55	55	55	55	42	
1953	25	55	55	55	55	43	
1954	25	55	55	55	55	44	
1955	25	55	55	55	55	45	
1956	25	55	55	55	55	46	
1957	25	55	55	55	55	47	
1958	25	55	55	55	55	48	
1959	25	55	55	55	55	49	
1960	25	55	55	55	55	50	
1961	25	55	55	55	55	51	
1962	25	55	55	55	55	52	
1963	25	55	55	55	55	53	
1964	25	55	55	55	55	54	
1965	25	55	55	55	55	55	
1966	25	55	55	55	55	56	
1967	25	55	55	55	55	57	
1968	25	55	55	55	55	58	
1969	25	55	55	55	55	59	
1970	25	55	55	55	55	60	
1971	25	55	55	55	55	61	
1972	25	55	55	55	55	62	
1973	25	55	55	55	55	63	
1974	25	55	55	55	55	64	
1975	25	55	55	55	55	65	
1976	25	55	55	55	55	66	
1977	25	55	55	55	55	67	
1978	25	55	55	55	55	68	
1979	25	55	55	55	55	69	
1980	25	55	55	55	55	70	
1981	25	55	55	55	55	71	
1982	25	55	55	55	55	72	
1983	25	55	55	55	55	73	
1984	25	55	55	55	55	74	
1985	25	55	55	55	55	75	
1986	25	55	55	55	55	76	
1987	25	55	55	55	55	77	
1988	25	55	55	55	55	78	
1989	25	55	55	55	55	79	
1990	25	55	55	55	55	80	
1991	25	55	55	55	55	81	
1992	25	55	55	55	55	82	
1993	25	55	55	55	55	83	
1994	25	55	55	55	55	84	
1995	25	55	55	55	55	85	
1996	25	55	55	55	55	86	
1997	25	55	55	55	55	87	
1998	25	55	55	55	55	88	
1999	25	55	55	55	55	89	
2000	25	55	55	55	55	90	
2001	25	55	55	55	55	91	
2002	25	55	55	55	55	92	
2003	25	55	55	55	55	93	
2004	25	55	55	55	55	94	
2005	25	55	55	55	55	95	
2006	25	55	55	55	55	96	
2007	25	55	55	55	55	97	
2008	25	55	55	55	55	98	
2009	25	55	55	55	55	99	
2010	25	55	55	55	55	100	

Table 5f
Subject No. 6

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>ΣX</u>
I	1	62	65	69	68	60	324
	2	64	63	69	68	68	332
	3	70	69	62	62	73	336
	4	67	67	66	73	67	340
	5	69	69	76	72	67	353
II	1	68	71	66	56	70	331
	2	65	67	65	68	68	333
	3	73	64	68	69	75	349
	4	69	68	69	71	75	352
	5	73	71	69	73	66	352
III	1	74	77	69	70	71	361
	2	69	77	81	74	73	374
	3	87	75	70	73	71	376
	4	68	77	78	81	83	387
	5	73	75	90	77	73	388
IV	1	91	86	92	105	93	467
	2	91	86	91	96	105	469
	3	105	93	97	88	93	476
	4	116	96	100	98	99	509
	5	125	113	112	111	105	566
V	1	144	109	98	101	109	561
	2	107	115	114	108	121	565
	3	117	112	119	113	112	573
	4	115	120	116	113	113	577
	5	112	112	118	120	116	578

TABLE 2

Continued on p. 6

Year	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023																										
I	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	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
II	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	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
III	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	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
IV	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	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
V	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	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100

Table 5g

Subject No. 7

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>Σ X</u>
I	1	49	44	46	49	49	237
	2	68	57	53	53	57	288
	3	69	69	61	53	49	301
	4	69	64	63	54	56	306
	5	74	67	79	74	78	372
II	1	64	53	51	49	50	267
	2	53	58	57	62	65	295
	3	65	61	62	65	54	307
	4	69	69	70	63	73	344
	5	77	67	74	70	70	358
III	1	67	70	67	63	60	327
	2	79	76	79	86	80	400
	3	95	99	82	84	88	448
	4	87	80	81	81	81	410
	5	71	83	88	75	92	409
IV	1	73	70	67	67	67	344
	2	80	77	83	75	83	398
	3	84	82	81	81	80	408
	4	95	91	93	69	76	424
	5	96	96	79	81	91	443
V	1	106	81	85	75	72	419
	2	94	76	95	92	103	460
	3	108	89	87	87	87	458
	4	96	98	108	108	112	522
	5	134	119	88	105	107	553

Table 5h
Subject No. 8

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>Σ X</u>
I	1	68	73	69	79	65	354
	2	73	73	78	72	70	366
	3	75	76	77	71	69	368
	4	92	100	96	88	102	478
	5	104	108	98	94	97	499
II	1	63	58	65	72	67	325
	2	69	66	71	56	65	327
	3	65	70	68	65	68	333
	4	73	77	76	77	69	372
	5	80	72	78	77	80	387
III	1	64	72	70	73	70	349
	2	70	70	72	72	70	354
	3	71	68	75	75	68	357
	4	70	70	72	73	73	358
	5	76	76	73	73	73	371
IV	1	77	81	76	84	80	398
	2	80	81	86	83	80	410
	3	86	85	86	85	86	428
	4	82	85	91	92	84	434
	5	96	88	84	85	89	442
V	1	96	93	107	99	93	488
	2	102	101	103	107	105	518
	3	109	112	104	101	94	520
	4	114	108	103	117	105	547
	5	111	127	121	126	116	601

Table 2
Continued on p. 3

Lower	Upper	I	II	III	IV	V	W
I	1	93	83	77	70	64	58
2	2	94	84	78	71	65	59
3	3	95	85	79	72	66	60
4	4	96	86	80	73	67	61
5	5	97	87	81	74	68	62
6	6	98	88	82	75	69	63
7	7	99	89	83	76	70	64
8	8	100	90	84	77	71	65
9	9	101	91	85	78	72	66
10	10	102	92	86	79	73	67
11	11	103	93	87	80	74	68
12	12	104	94	88	81	75	69
13	13	105	95	89	82	76	70
14	14	106	96	90	83	77	71
15	15	107	97	91	84	78	72
16	16	108	98	92	85	79	73
17	17	109	99	93	86	80	74
18	18	110	100	94	87	81	75
19	19	111	101	95	88	82	76
20	20	112	102	96	89	83	77
21	21	113	103	97	90	84	78
22	22	114	104	98	91	85	79
23	23	115	105	99	92	86	80
24	24	116	106	100	93	87	81
25	25	117	107	101	94	88	82
26	26	118	108	102	95	89	83
27	27	119	109	103	96	90	84
28	28	120	110	104	97	91	85
29	29	121	111	105	98	92	86
30	30	122	112	106	99	93	87
31	31	123	113	107	100	94	88
32	32	124	114	108	101	95	89
33	33	125	115	109	102	96	90
34	34	126	116	110	103	97	91
35	35	127	117	111	104	98	92
36	36	128	118	112	105	99	93
37	37	129	119	113	106	100	94
38	38	130	120	114	107	101	95
39	39	131	121	115	108	102	96
40	40	132	122	116	109	103	97
41	41	133	123	117	110	104	98
42	42	134	124	118	111	105	99
43	43	135	125	119	112	106	100
44	44	136	126	120	113	107	101
45	45	137	127	121	114	108	102
46	46	138	128	122	115	109	103
47	47	139	129	123	116	110	104
48	48	140	130	124	117	111	105
49	49	141	131	125	118	112	106
50	50	142	132	126	119	113	107

Table 5i
Subject No. 9

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>ΣX</u>
I	1	52	50	49	43	45	244
	2	53	46	49	50	46	244
	3	54	53	46	48	45	244
	4	62	64	59	56	53	299
	5	92	77	72	66	67	374
II	1	53	58	58	54	50	273
	2	69	63	64	65	63	324
	3	62	64	70	68	66	330
	4	70	68	63	70	65	336
	5	93	88	80	70	65	396
III	1	69	70	69	62	59	329
	2	73	70	74	74	70	361
	3	81	77	76	70	77	381
	4	84	89	79	80	89	421
	5	60	84	84	89	86	423
IV	1	90	99	97	99	96	481
	2	100	103	102	94	91	490
	3	104	104	104	93	90	498
	4	105	106	101	98	100	510
	5	113	110	107	105	96	531
V	1	112	113	103	108	112	548
	2	115	104	115	108	120	562
	3	121	108	112	112	116	569
	4	126	131	130	121	122	630
	5	146	139	140	140	139	704

25 1000

S. m. 1000

<u>Σ</u>	<u>Σ</u>	<u>Σ</u>	<u>Σ</u>	<u>Σ</u>	<u>Σ</u>	<u>Σ</u>	<u>Σ</u>
142	14	14	14	14	14	14	I
144	14	14	14	14	14	14	II
146	14	14	14	14	14	14	III
148	14	14	14	14	14	14	IV
150	14	14	14	14	14	14	V
152	14	14	14	14	14	14	
154	14	14	14	14	14	14	
156	14	14	14	14	14	14	
158	14	14	14	14	14	14	
160	14	14	14	14	14	14	
162	14	14	14	14	14	14	
164	14	14	14	14	14	14	
166	14	14	14	14	14	14	
168	14	14	14	14	14	14	
170	14	14	14	14	14	14	
172	14	14	14	14	14	14	
174	14	14	14	14	14	14	
176	14	14	14	14	14	14	
178	14	14	14	14	14	14	
180	14	14	14	14	14	14	
182	14	14	14	14	14	14	
184	14	14	14	14	14	14	
186	14	14	14	14	14	14	
188	14	14	14	14	14	14	
190	14	14	14	14	14	14	
192	14	14	14	14	14	14	
194	14	14	14	14	14	14	
196	14	14	14	14	14	14	
198	14	14	14	14	14	14	
200	14	14	14	14	14	14	

Table 5i
Subject No. 10

<u>Lever</u>	<u>Torque</u>	<u>X₁</u>	<u>X₂</u>	<u>X₃</u>	<u>X₄</u>	<u>X₅</u>	<u>ΣX</u>
I	1	51	53	55	50	57	266
	2	58	50	58	57	57	280
	3	58	61	62	65	70	318
	4	63	62	62	65	57	309
	5	62	57	61	67	65	312
II	1	62	59	65	66	62	314
	2	65	63	61	62	65	318
	3	62	63	64	69	63	321
	4	65	64	66	71	66	332
	5	62	71	70	80	77	360
III	1	61	61	65	65	62	314
	2	58	66	65	65	61	315
	3	64	61	61	63	64	313
	4	71	66	65	67	70	339
	5	67	62	73	70	73	345
IV	1	80	81	81	85	83	410
	2	80	88	87	81	77	413
	3	83	72	84	89	90	418
	4	86	83	72	89	86	418
	5	91	89	94	81	82	437
V	1	88	87	92	88	92	447
	2	77	78	85	80	87	407
	3	77	82	80	82	88	409
	4	88	96	88	88	83	443
	5	92	84	86	89	89	440

APPENDIX C

Analysis of Variance

The following steps were observed:

1. Computation of the within-cell variation --

$$\sum_{1}^{250} \frac{\sum_{1}^5 (\Sigma X^2)}{1} - \frac{\sum_{1}^{250} (\Sigma X)^2}{5}$$

where X = each single measurement in a cell; that is, a series of five results corresponding to a combination of lever and torque for one operator.

$$\text{Within-cell variation} = 7625974 - 7803399.2 = 22574.8$$

2. Computation of average measurement error --

$$\text{Average measurement error} = \frac{22574.8}{1250-250} = 22.5748$$

3. Computation of variation among torques (Q_T) -

$$Q_T = \frac{T_1^2 + T_2^2 + T_3^2 + T_4^2 + T_5^2}{250} - \frac{T^2}{1250}$$

where T_1 = total of all totals for torque 1

T_2 = total of all totals for torque 2, etc.

T = grand total of these.

$$Q_T = \frac{1836613308}{250} - \frac{9145096900}{1250}$$

$$Q_T = 30375.704$$

APPENDIX B

ANALYSIS OF VARIANCE

The following steps were followed:

1. Computation of the within-cell variation -

$$SS_{within} = \sum_{i=1}^k \sum_{j=1}^n (x_{ij} - \bar{x}_{i.})^2$$

where i = each single measurement in a cell; j =

each of five levels of temperature in

a combination of level and factor for one

operator.

2. Computation of average measurement error -

3. Computation of average measurement error -

$$ME = \frac{SS_{within}}{N - k}$$

4. Computation of variation among between (S_B) -

$$S_B = \sum_{i=1}^k \frac{n_i \bar{x}_{i.}^2}{n} - \frac{(\sum_{i=1}^k n_i \bar{x}_{i.})^2}{N}$$

where n_i = total of all totals for factor i

$\bar{x}_{i.}$ = total of all totals for factor i , etc.

N = grand total of observations

$$S_T = \sum_{i=1}^k \sum_{j=1}^n x_{ij}^2 - \frac{(\sum_{i=1}^k \sum_{j=1}^n x_{ij})^2}{N}$$

$$S_T = S_B + S_W$$

4. Computation of variation among levers (Q_1) --

$$Q_1 = \frac{T_I^2 + T_{II}^2 + T_{III}^2 + T_{IV}^2 + T_V^2}{250} - \frac{T^2}{1250}$$

where T_I = total of all totals for lever I, etc.

T = grand total of these.

$$Q_1 = \frac{1906595980}{250} - \frac{9145096900}{1250} = 310306.4$$

5. Computation of variation among individuals (Q_1) --

$$Q_1 = \frac{T_a^2 + T_b^2 + \dots + T_j^2}{125} - \frac{T^2}{1250}$$

where T_a = total of all totals for individual a, etc.

T = grand total of these.

$$Q_1 = \frac{926226136}{125} - \frac{9145096900}{1250} = 98531.568$$

6. Computation of variation for torques versus levers (Q_{T1}) --

$$Q_{T1} = \frac{T_{II}^2 + T_{III}^2 + \dots + T_{IV}^2 + T_{2I}^2 + \dots + T_{5V}^2}{50} - \frac{T^2}{1250} - Q_T - Q_1$$

where T_{II} = total of totals of individuals for torque 1 and lever I, etc.

T = grand total of these.

$$Q_{T1} = \frac{382935940}{50} - \frac{9145096900}{1250} - 30375.704 - 310306.4 = 1959.176$$

7. Computation of variation for torques versus individuals (Q_{T1}) --

$$Q_{T1} = \frac{T_{1a}^2 + \dots + T_{1j}^2 + T_{2a}^2 + \dots + T_{5j}^2}{25} - \frac{T^2}{1250} - Q_T - Q_1$$

where T_{1a} = total of totals for torque 1 and individual a for all levers, etc.

6. Computation of variance among layers (σ_{L}^2) --

$$\sigma_{L}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{k-1}$$

where $\sum_{i=1}^k N_i$ = total of all layers for factor A, etc.

N = grand total of observations

$$\sigma_{L}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{k-1}$$

7. Computation of variance among individuals (σ_{I}^2) --

$$\sigma_{I}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{N-k}$$

where $\sum_{i=1}^k N_i$ = total of all layers for individual A, etc.

N = grand total of observations

$$\sigma_{I}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{N-k}$$

8. Computation of variance for between versus layers (σ_{L}^2) --

$$\sigma_{L}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{k-1}$$

$$\sigma_{L}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{k-1}$$

where $\sum_{i=1}^k N_i$ = total of layers of individuals for factor A, etc.

N = grand total of observations

$$\sigma_{L}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{k-1}$$

$$\sigma_{L}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{k-1}$$

9. Computation of variance for between versus individuals (σ_{I}^2) --

$$\sigma_{I}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{N-k}$$

$$\sigma_{I}^2 = \frac{\sum_{i=1}^k \frac{N_i^2}{N} - \frac{(\sum_{i=1}^k N_i)^2}{N}}{N-k}$$

where $\sum_{i=1}^k N_i$ = total of layers for factor A and individual

A for all layers, etc.

T = grand total of these.

$$Q_{T1} = \frac{186232615}{25} - \frac{9145096900}{1250} - 30375.704 - 98531.568$$

$$= 4319.808$$

8. Computation of variation for levers versus individuals

(Q_{1i}) --

$$Q_{1i} = \frac{T_{Ia}^2 + \dots + T_{Ij}^2 + \dots + T_{V1}^2}{25} - \frac{T^2}{1250} - Q_1 - Q_i$$

where T_{Ia} = total of totals of individual a and lever I
for all torques, etc.

T = grand total of these.

$$Q_{1i} = \frac{193957344}{25} - \frac{9145096900}{1250} - 310306.4 - 98531.568$$

$$= 33390.28$$

9. Computation of variation for torques versus individuals
versus levers (Q_{T11}) --

$$Q_{T11} = \frac{\text{Sum of squares of sums for each individual on
one torque and one lever}}{5}$$

$$= \frac{T^2}{1250} - Q_T - Q_1 - Q_i - Q_{T1} - Q_{T1} - Q_{11}$$

$$Q_{T11} = \frac{39016976}{5} - \frac{9145096900}{1250} - 30375.754 - 310306.4$$

$$- 98531.568 - 1959.176 - 4319.808 - 33390.28$$

$$= 8434.744$$

10. Computation of F's for each variation and test of significance.

The results are shown in Table 6 which follows.

7. A group of boys = T

$$100.0000 - 100.0000 = 0.000000 = \frac{0.000000}{100} = 0.000000$$

$$0.000000 =$$

8. Computation of variation for factor versus individual

$$I^2 = \frac{\sum (I_{ij} - \bar{I})^2}{\sum I^2} = \frac{\sum I_{ij}^2 - \frac{(\sum I_{ij})^2}{N}}{\sum I^2}$$

where I_{ij} = total of units of individual i and factor j

for all factors, etc.

9. A group of boys = T

$$100.0000 - 100.0000 = 0.000000 = \frac{0.000000}{100} = 0.000000$$

$$0.000000 =$$

10. Computation of variation for factor versus individual

$$I^2 = \frac{\sum (I_{ij} - \bar{I})^2}{\sum I^2}$$

$$I^2 = \frac{\sum I_{ij}^2 - \frac{(\sum I_{ij})^2}{N}}{\sum I^2}$$

$$I^2 = \frac{\sum I_{ij}^2 - \frac{(\sum I_{ij})^2}{N}}{\sum I^2}$$

$$I^2 = \frac{\sum I_{ij}^2 - \frac{(\sum I_{ij})^2}{N}}{\sum I^2}$$

$$I^2 = \frac{\sum I_{ij}^2 - \frac{(\sum I_{ij})^2}{N}}{\sum I^2}$$

$$I^2 =$$

11. Computation of I^2 for each variable and test of significance

Results

The results are shown in table 2 which follows.

Table 2. Results of the analysis of variance for the factors

Table 6
General Results of the Analysis
of Variance

<u>Quantity</u>	<u>Value</u>	<u>D.F.</u>	<u>Mean Square</u>	<u>F</u>	<u>Signif- icance</u>
Q_T	30375.704	4	7593.926	336.389	*
Q_1	310306.400	4	77576.600	3436.424	*
Q_1	98531.568	9	10947.952	484.963	*
Q_{T1}	1959.176	16	122.448	5.424	*
Q_{T1}	4319.908	36	119.946	5.313	*
Q_{11}	33390.280	36	927.507	41.086	*
Q_{T11}	8434.744	144	58.575	2.595	*
Error	22574.800	1000	22.575		

* - means: significant value.

Table 7
Limits for Levels 5% and 1%

<u>Level</u>	<u>D.F.</u>	<u>4</u>	<u>9</u>	<u>16</u>	<u>36</u>	<u>144</u>
5%		2.38	1.89	1.65	1.43	1.23
1%		3.34	2.43	2.01	1.57	1.33

Table gives levels for D.F. shown versus D.F. = 1000.

Table 1
General Results of the Analysis
of the Data

Year	I	Value	S.D.	Value	Year
1950	100.0	100.0	1.0	100.0	1950
1951	100.0	100.0	1.0	100.0	1951
1952	100.0	100.0	1.0	100.0	1952
1953	100.0	100.0	1.0	100.0	1953
1954	100.0	100.0	1.0	100.0	1954
1955	100.0	100.0	1.0	100.0	1955
1956	100.0	100.0	1.0	100.0	1956
1957	100.0	100.0	1.0	100.0	1957
1958	100.0	100.0	1.0	100.0	1958
1959	100.0	100.0	1.0	100.0	1959
1960	100.0	100.0	1.0	100.0	1960

* - means significant value

Table 2
Results for the Analysis of the Data

Year	I	Value	S.D.	Value	Year
1950	100.0	100.0	1.0	100.0	1950
1951	100.0	100.0	1.0	100.0	1951

Table gives results for the analysis of the data for the years 1950-1960.

APPENDIX D

Determination of the best representative curves of the results of the experiment.

The method of the least squares was adopted and the following equations used to determine the parameters of the straight lines $Y = a + bX$:

$$a = \frac{(\sum Y)(\sum X^2) - (\sum X)(\sum XY)}{N\sum X^2 - (\sum X)^2}$$

$$b = \frac{N\sum XY - (\sum X)(\sum Y)}{N\sum X^2 - (\sum X)^2}$$

The results found for the two groups of curves are presented in Table 8 and Table 9. It was found by use of the appropriate test that departure from linearity is not significant for the curves $t = f(l)$ and $t = F(T)$.

SECTION 2

Definition of the test statistic and its distribution under the null hypothesis.

The test of the linear hypothesis is based on the following statistics used to determine the parameters

$$Y = X\beta + \epsilon$$

$$\frac{1}{n} \sum_{i=1}^n \frac{X_i^2}{X_i} - \frac{(\sum_{i=1}^n X_i)^2}{n^2} = s$$

$$\frac{1}{n} \sum_{i=1}^n \frac{X_i^2}{X_i} - \frac{(\sum_{i=1}^n X_i)^2}{n^2} = s$$

The results found for the two groups of values are presented in Table 2 and Table 3. It can be seen from the results that the test statistic is not significant for the values $\beta = 0$ and $\beta = 1$.

Table 8

Slopes and intercepts for the best fitting straight lines
for $t = f(l)$ for $T = \text{constant}$.

T	28	59	89	112	145
a	0.2635	0.2970	0.3235	0.3612	0.4035
b	0.03129	0.03131	0.03125	0.03140	0.03238

Table 9

Slopes and intercepts for the best fitting straight lines
for $t = f(l)$ for $l = \text{constant}$.

l	10	12	15	20	25
a	0.5337	0.6154	0.6670	0.8409	1.0039
b	0.001690	0.001031	0.001137	0.001146	0.001628

Table 1

Slopes and intercepts for the best fitting straight lines for $y = f(x)$ for $I = constant$.

I	m	b	c	d
1	0.00180	0.00121	0.00130	0.00140
2	0.00180	0.00121	0.00130	0.00140
3	0.00180	0.00121	0.00130	0.00140
4	0.00180	0.00121	0.00130	0.00140

Table 2

Slopes and intercepts for the best fitting straight lines for $y = f(x)$ for $I = constant$.

I	m	b	c	d
1	0.00180	0.00121	0.00130	0.00140
2	0.00180	0.00121	0.00130	0.00140
3	0.00180	0.00121	0.00130	0.00140
4	0.00180	0.00121	0.00130	0.00140

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