INVESTIGATION OF CRANKING MOTIONS

by

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INTRODUCTION

Progress in Industrial Engineering has consistently been closely associated with progress in measurement. The accuracy required for interchangeable parts in modern precision equipments became a reality only after years of development, refinement, and research in the field of measurement. The Standard Units for linear dimensions were at one period in history such inaccurate measures as "width of a man's hand", "the length of a man's foot", or "the normal reach of a man's arm". When accurate standards based on the Standard Yard were comparatively recently accepted universally, there remained a serious problem in developing instruments that would measure small divisions accurately.

Mass production has emphasized the paramount importance of human relations in industry. Understanding and agreement between individuals demand an accurate measure of human effort and accomplishment. Time Study with primary emphasis on Work Simplification has proven so near the answer that it has been subject to unwarranted claims and therefore unjust criticism. Instruments for measuring the accomplishment of individuals have been developed to accuracies beyond ordinary demand. However, the level of performance of the individual remains purely a matter of human judgement, unless supported by extensive data taken from the measurement of a large number of individuals representing a true cross section of industrial workers.

Industrial Engineers have developed remarkable skill in judging the performance of individuals in relation to that which can be expected from the average worker who has been reasonably selected and reasonably trained, but similar skill might have been developed in judging the "width of the average man's hand" or "the length of the average man's arm". An equitable measure of the time required to perform specific tasks demands a generally accepted standard that can be applied directly to the motions used in performing the task. We would then have a unit of measure with no more reason for objection than there might be today by someone who thought the yard should be somewhat longer or somewhat shorter than the accepted standard.

"Methods-time measurement is a procedure which analyzes any manual operation or method into the basic motions required to perform it and assigns to each motion a predetermined time standard which is determined by the nature of the motion and the conditions under which it is made." The principles of the procedure and some of the standard times for many of the common motions are given in Methods-Time Measurement[1] by Harold B. Maynard, G. J. Stegmerten, and John L. Schwab, and published by the McGraw-Hill Book Company 1948. The definition of the procedure quoted above appears on Page 12 of that book. The authors do not claim to have established the correct standards in all cases. They have invited industrial, research, and educational institutions to cooperate in determining times that can and should be generally accepted as the Standard Time for each motion.

The accumulation of date with a view toward establishing standard times is a worthy activity that will influence progress in the same degree other accurate measurements continue their influence. To add just a little contribution to the ultimate objective of this work was considered an ambitious goal for this investigation.

II
REVIEW OF LITERATURE

Literature on Cranking Motions is very limited. The publication on Methods-time measurement[1] does not discuss Cranking. Later Table 9 was published, giving Standard Times for turning cranks from 1 to 10 inches in diameter in increments of 1 inch, and from 10 to 20 inches in increments of 2 inches. No details of the apparatus used or the method of determining the times have been found. In any case an investigation without prejudice was preferred.

The Special Devices Center of the Office of Naval Research has had a number of studies made to establish the conditions, placement, and orientation of control cranks to permit maximum performance. None was found dealing with the standard or normal time required. The discussion by K. O. W. Sandberg and H. L. Lipschultz on their problem "Relative Performance for Cranking a Hand Wheel at Different Positions on a Vertical Surface"[3] published in pamphlet form by the Industrial Engineering Laboratory of New York University was helpful in considering conditions and variables to be studied in this investigation.

The report published by The Journal Press, Provincetown, Massachusetts of the work by John David Reed on the "Factors Influencing Rotary Performance"[2] was helpful in anticipating the factors involved in the overall problem of cranking motions. The report concentrated on maximum performance, rather than normal times. Conclusions on the disadvantages of using the non-preferred hand were to be expected, but would be required very infrequently in industry.

III
THE INVESTIGATION

A. Objective

The field of investigation relative to cranking motions is extensive. There are many variables that might occur in applications. It is generally accepted that the diameter of the crank and the braking force are the major factors in altering cranking performance. The Methods-time data table was published for varied diameters. It was felt the greatest contribution toward the most prompt general acceptance of a standard would result if the times published could be verified. It is then necessary to establish the conditions under which the motion is made. This can best be done by establishing the limits of all the possible variables in cranking applications. The most common variables should be investigated first, extending them to include any one found or anticipated in the field as rapidly as possible.

The objective in this investigation was to measure the time required for an average operator to turn a crank under average conditions, and discover whether the data substantiates standard times published by the Methods Engineering Council. The objective also included investigation of the variables most commonly found in practical applications. It was realized that the most important variables might be dictated by conditions arising in the investigation, but such things as height from the floor, angle of crank, brake load, and cranking to a line were anticipated.

B. Method of Procedure

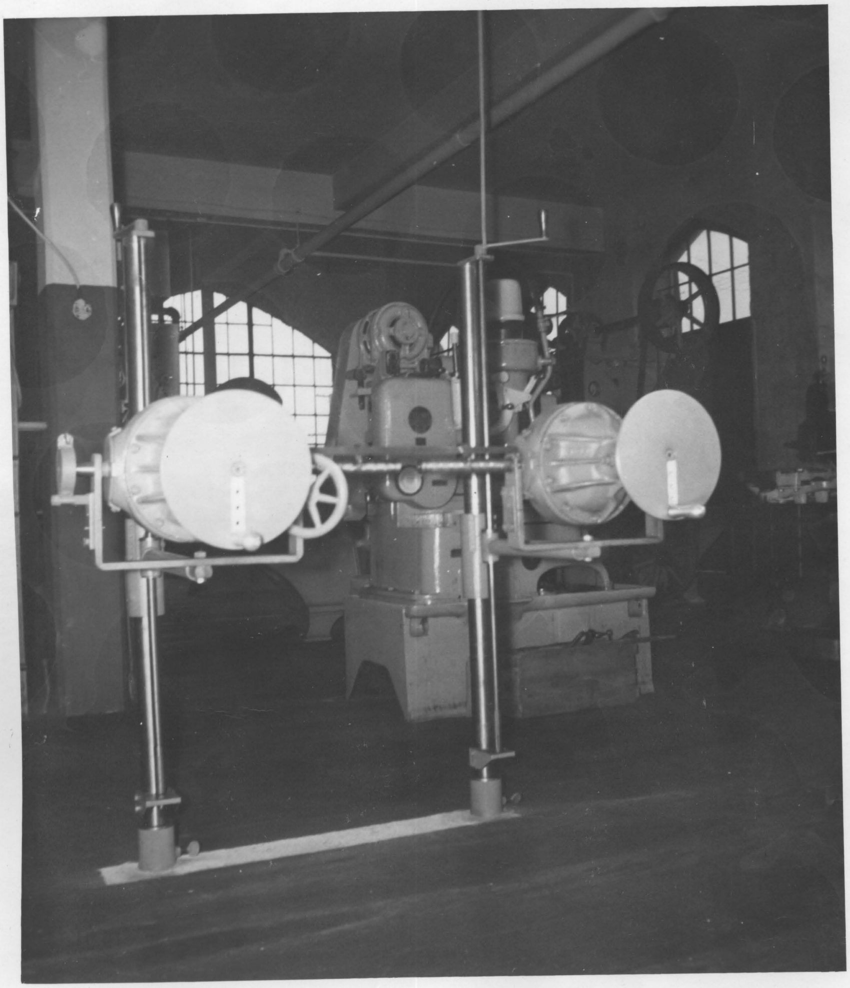
1. Apparatus

The equipment on which the cranking was done was constructed by mounting an automobile differential on a column. Two machines were built, three feet apart, to permit cranking simultaneously with both hands. Figure 1 illustrates the apparatus. The differential was mounted on a bracket with a girdle around the column and a screw to raise and lower the bracket. Figures 2 and 3 show the machine at different distances from the floor.

The bracket could be swung about the column similar to a radial drill press, giving different angles of cranking relative to the body of the operator, as illustrated in Figures 4 and 5

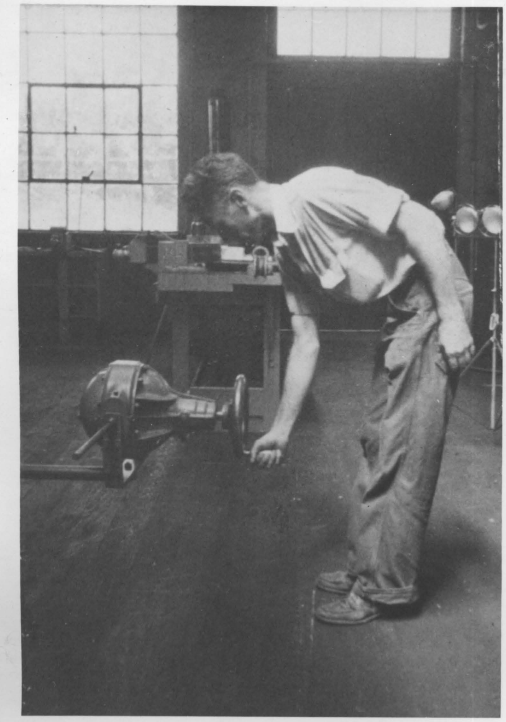
The differential housing was mounted on a trunnion on the end of the bracket to permit adjustment of the vertical angle of the crank, that is, the plane of the crank relative to the floor. Figure 6 illustrates the extreme angles possible, and Figure 7 angles that would be met more commonly.

The differential gears were locked to prevent differential action, but giving positive drive to both axles. A brake drum was attached to one axle, with a brake band anchored to the housing. A thumb screw was used to tighten the brake band to the desired force on the crank. Figure 8 illustrates the brake mechanism. The force required on the



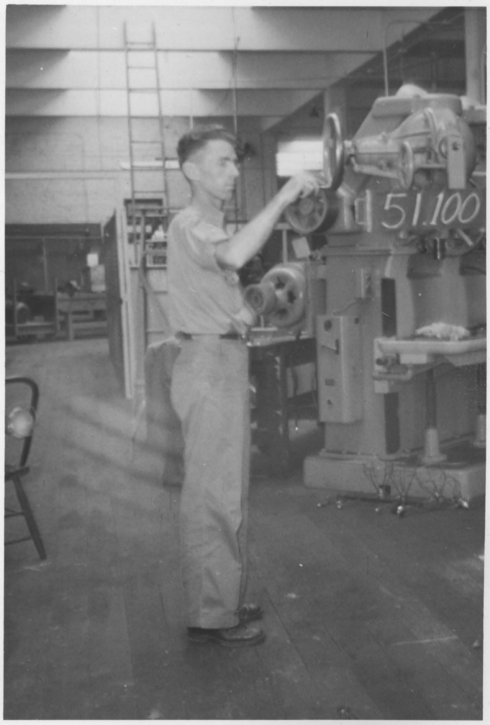
Cranking Machines

Figure 1.



Height from floor 22"

Figure 2.



Height from floor 64"

Figure 3.

Angular Setting

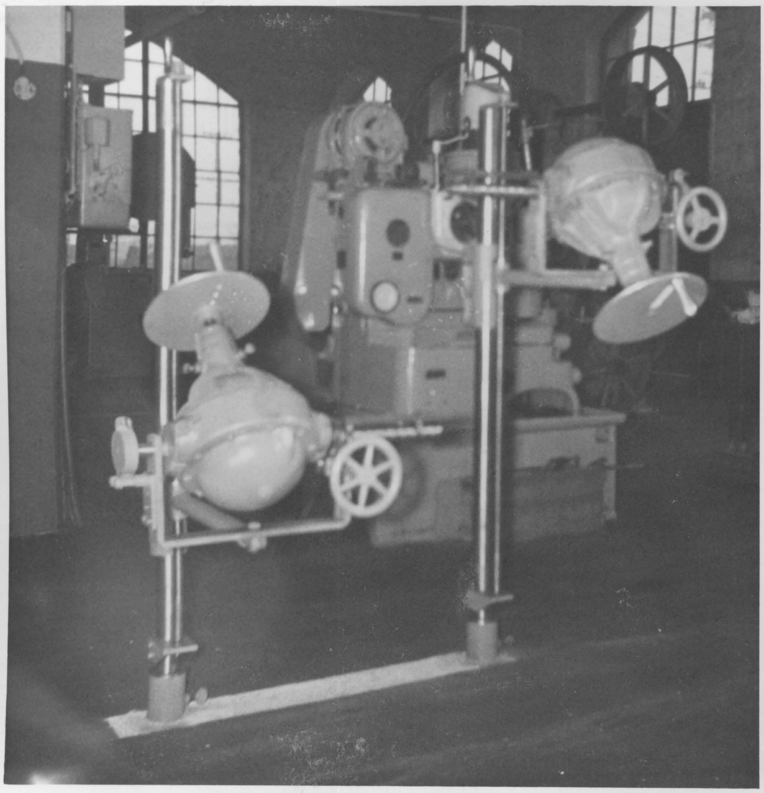
45° to Operator

Figure 4.

Angular Setting

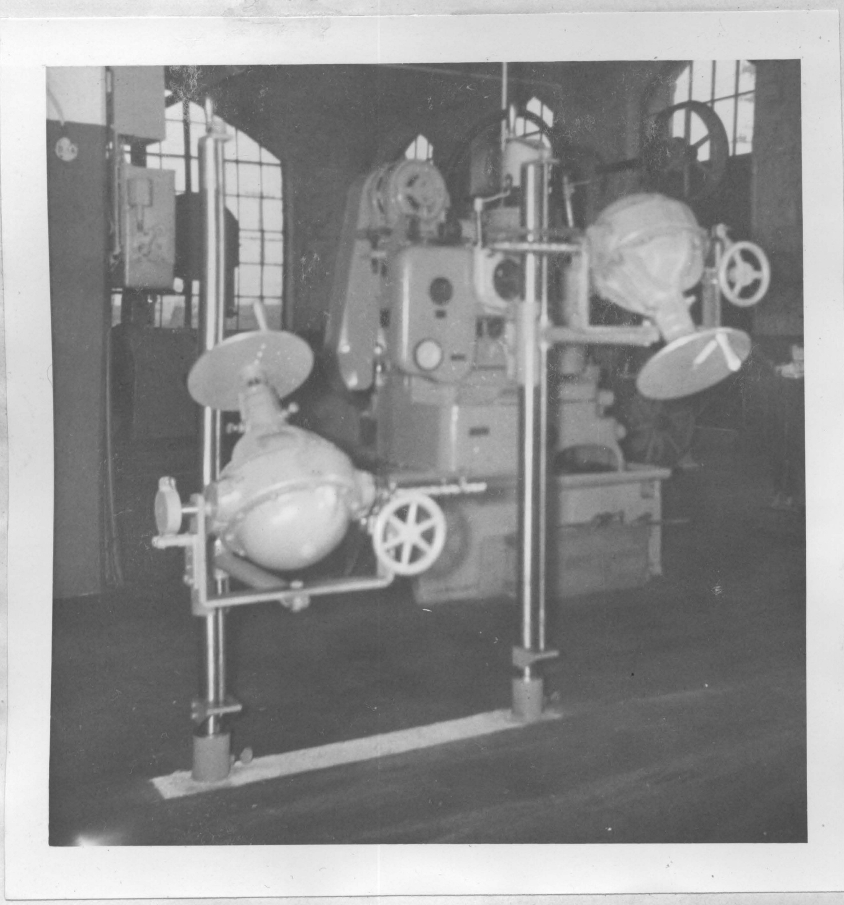
90° to Operator

Figure 5.



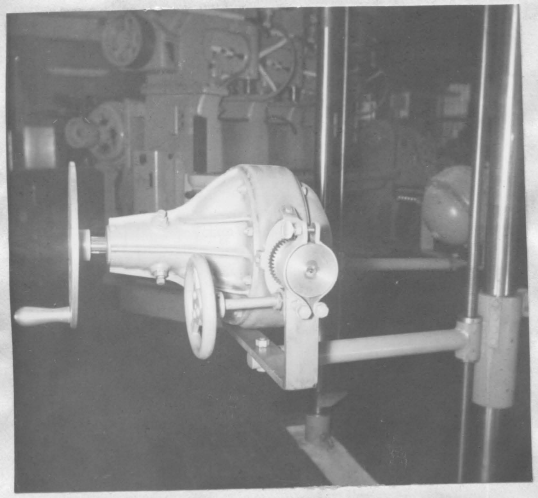
Extreme Angles, to floor

Figure 6.



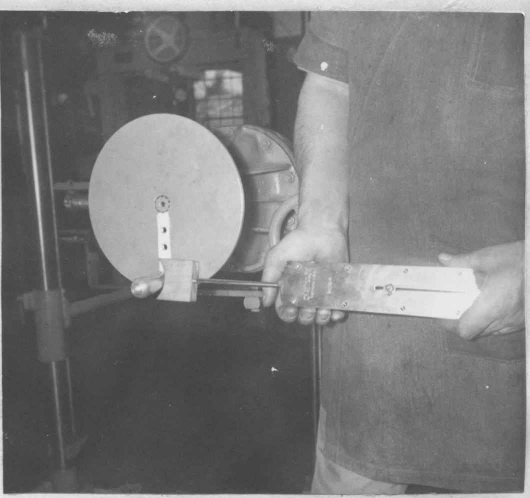
Angular Settings, to floor

Figure 7.



Brake

Figure 8.



Force Measurement

Figure 9.

crank handle was taken as a more critical measure of the cranking action than was brake load in foot-pounds. The force was measured with a Push Pull Gage, Figure 9.

The axle opposite the brake was threaded. A pointer follower was actuated by the thread with the pointer traveling along a blank scale on which could be placed a line at any point, Figure 10. The line position could be varied in order to require mental reaction time in each trial rather than permitting the operator to memorize the exact crank location where he should stop in coming to a fixed line.

2. Preliminary Investigation and Analysis of Variances

It was proposed to collect data for the investigation by analyzing motion picture film taken with an electric drive 8 mm., Measurement Cino-Kodak, but there remained a question as to the best speed for the study. A preliminary run was made as an aid in deciding this question and other details of the methods to be used, as well as to discover any conditions demanding control that had not been anticipated.

Another question calling for a decision was the number of revolutions of the crank that should be made in each trial. Sandberg and Lipschultz[3] found a noticeable increase in time for a revolution after continuous cranking for more than 30 seconds. They investigated maximum performance where this study is interested in normal effort. Under conditions an-

Pointer

Figure 10.

ticipated in this investigation, 60 or more revolutions would be made before reaching the point where a noticeable change would occur. One run of 40 revolutions was made without a noticeable increase in the time for each revolution. In industry sustained cranking will usually be mechanized and hand cranking done only for relatively short adjusting operations. It was considered adequate to make a detailed analysis of 18 turns to discover any trend between revolutions.

Motion pictures were taken of one operator with the camera running at 1000 frames per minute and with it running at 4000 frames per minute. One of the mechanics in the VPI machine shop turned the crank 18 revolutions, starting from rest and bringing the crank to a complete stop. Six runs were made with the plane of the crank parallel to the operator's body and six with the crank perpendicular, 90°, to his body. Three runs at each angle were photographed at 1000 FPM and three 4000 FPM. This gave a total of 216 times for turning a crank one revolution. The analysis of variance is tabulated in Table 1.

The analysis of additional revolutions with 15 degrees of freedom, i.e. between revolutions excluding the first and last, is a breakdown of the 17 degrees of freedom between all revolutions. The data for the analysis of variance between individuals was taken from a later run of a large number of operators. It is distinct from the preliminary experiment.

Table 1

Analysis of Variance

	Degrees of Freedom	Sum of squares	Variance
Between trials by one operator	2	.000,006,45	.000,003,22
Parallel vs 90° to operator's body	1	.000,016,80	.000,016,80
1000 frames per minute vs 4000 FPM	1	.000,000,09	.000,000,09
Between revolutions	17	.000,214,44	.000,012,61
Interactions	194	.000,064,39	.000,000,33
Total	215	.000,302,17	
Between revolutions excluding 1st & last	15	.000,000,88	.000,000,06
Between first and last revolution	1	.000,014,65	.000,014,65
First and last vs additional turns	1	.000,198,91	.000,198,91
Total between revolutions	17	.000,214,44	
Between individuals	92	.000,258,43	.000,002,81

The analysis showed that there was no significant advantage in running the camera at 4000 frames per minute, while of course 1000 FPM had a four to one advantage in the film required and time for analysis of the film.

Variability within the additional revolutions was somewhat less than the inherent variability of the experiment. The first and last turns were radically different from the additional turns and from each other. A significant difference in the first and in the last turn was anticipated, but it was thought possible that others, perhaps the second or the next to last, might also show a significant difference. In view of the preliminary experiment and the analysis it was decided to average only five revolutions except in special cases to be discussed later.

The variability between different trials by one operator and between trials by different operators were found comparable. The decision to use five different operators can be considered arbitrary, but it is in accordance with common practice.

3. Method of Analysis

The motion pictures were analyzed by projecting the film onto a beaded screen with a Keystone Projector. The projector was equipped with a hand crank and a counter. With the short cycles involved, the hand crank was preferred over the electric control box. This was arranged to reduce with each turn, permitting a direct substraction for the time interval in thousandths of a minute. Kodachrome film proved to be a definite advantage in accurately distinguishing the exact frame for finger motions. The flesh color of the hand gave a clear contrast against the machine parts. The outline of the fingers and slight motion was much clearer than with ordinary black and white, where the two are only slightly different shades of gray.

The film having been exposed at 1000 frames per minute, gave a time interval of 0.00100 minutes between frames. Graphs of data where the readings were in even thousandths of a minute, i.e., in multiples of one hundred hundredths of thousandths of a minute, were plotted using a time scale of one half inch for each 100 hundredths of thousandths of a minute. The time for each additional revolution was taken from the average of five additional turns made in the trial, therefore resulted in times in multiples of 0.00020 hundredths of thousandths of a minute. The times for additional turns showed less variability than did the times for the first turns and the last revolution, resulting in a much closer cluster. To show the data more clearly, charts for additional revolutions were plotted using a time scale of one inch for each 100 hundredths of thousandths of a minute. This must be kept in mind in comparing any trends for additional revolutions with the trends for the first or last revolution.

C. Conclusions

It was decided the best results would be obtained by projecting 8 mm, kodachrome film, taken at 1000 frames per minute.

About 100 individuals from the students, staff members of the industrial engineering department, and shop mechanics at Virginia Polytechnic Institute, cranking as nearly as possible with normal effort, was thought would give a good average time.

Investigation of variables, in most cases, were to be made with five mechanics.

Each trial was to include a first revolution, five additional or intermediate turns, and a last revolution. Several exceptions to this last decision were expected, but they will be discussed under the investigation involved.

V
DISCUSSION OF RESULTS

A. Normal Times

In this study the commonly accepted definition of a Normal Time is used, namely, the time required by an operator of average skill, reasonably selected and reasonably trained, working with average effort, to make the motion under average conditions.

1. Average Conditions

One objective of this investigation was to measure the time required for an average operator to turn a crank under average conditions. The time indicated was then to be compared with the methods-time data published by the Methods Engineering Council for use in Methods-Time Measurement.

To find the prevailing average relative to each condition under which cranking is done would have required extensive investigation. It was only important to have a point of comparison that was reasonable and not at some extreme. Hence no investigation was made to determine the actual average crank diameter, brake load, height from the floor, or any other condition existing in industrial applications of cranking. Instead, average conditions were taken from experience.

Nine inches was selected for the diameter of the crank on the basis of a general impression that it would be close to a normal size. It certainly is not an extreme, regardless of the actual average of all cranks used in industry Nine inches for the diameter of the crank is one point that appears in the methods-time data tables and therefore can be compared directly with the present standard.

Most applications require a measurable force to turn the crank. Again, the average for all applications in industry or the universe is unknown but it was judged from experience that four pounds was a reasonable condition. In the same way about waist high or 36 inches from the floor, with the plane of the crank parallel to the operator's body were considered normal conditions.

2. Average Operator

A proper group for time study should preferably be reasonably selected, reasonably trained, and exert normal effort. A cross section of the student body at a technical institution should give a good average. Possible opinion that they do not represent normal is appreciated. They may have been from an above normal group, but they had not been selected for their dexterity or aptitude for the type of activity under investigation, nor had they had even average training in the motions involved. They all had some training in shop work but no appreciable experience. A group estimate of normal effort was used to pace them at a rate that could be maintained indefinitely. The shop men used for other investigations were included as well as members of the industrial engineering staff. Approximately one hundred individuals were considered a good number in view of the time required and the accuracy of results from the data.

3. Method of Investigation of Normal Times

For average times, an analysis of the first turn, five additional turns, and a last turn, was considered sufficient. Losses at the ends of rolls and due to defective developing of the film, resulted in 93 loops that could be analyzed. Therefore, data was collected from motion pictures of 93 individuals, turning a nine inch diameter crank, 36 inches from the floor, parallel to the operator's body with a four pound brake load.

4. Results from Investigation of Normal Times

The frequency distribution of the time taken by 93 individuals for the first revolution is charted in Figure 11, and the average for five additional revolutions in Figure 12. The average for the first revolution was 0.01070 minutes, and for the succeeding revolutions was 0.00802 minutes. The average time for the last revolution was 0.01139 minutes and is charted in Figure 13.

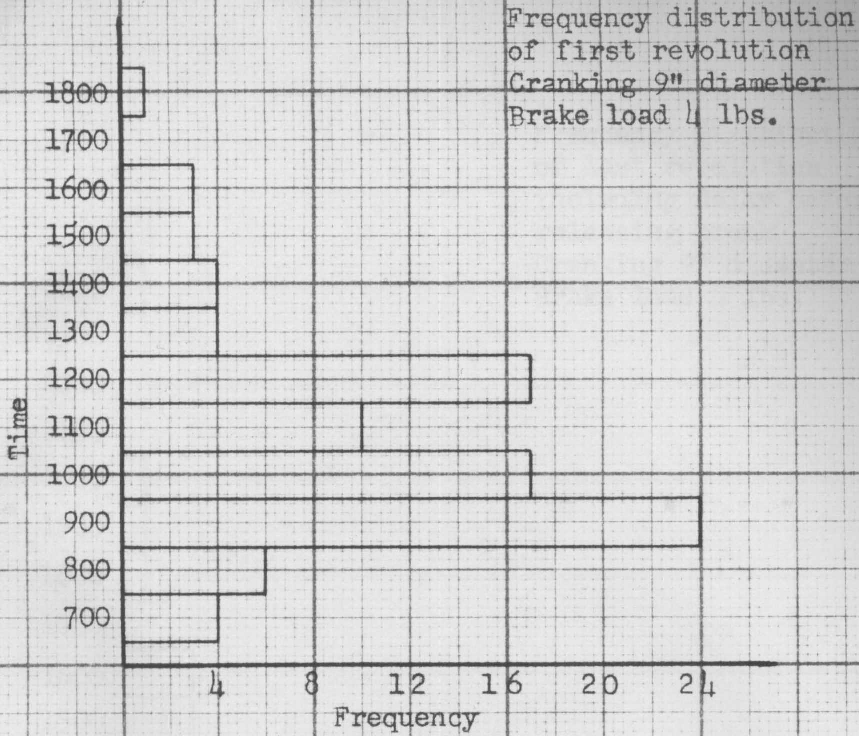


Figure 11.

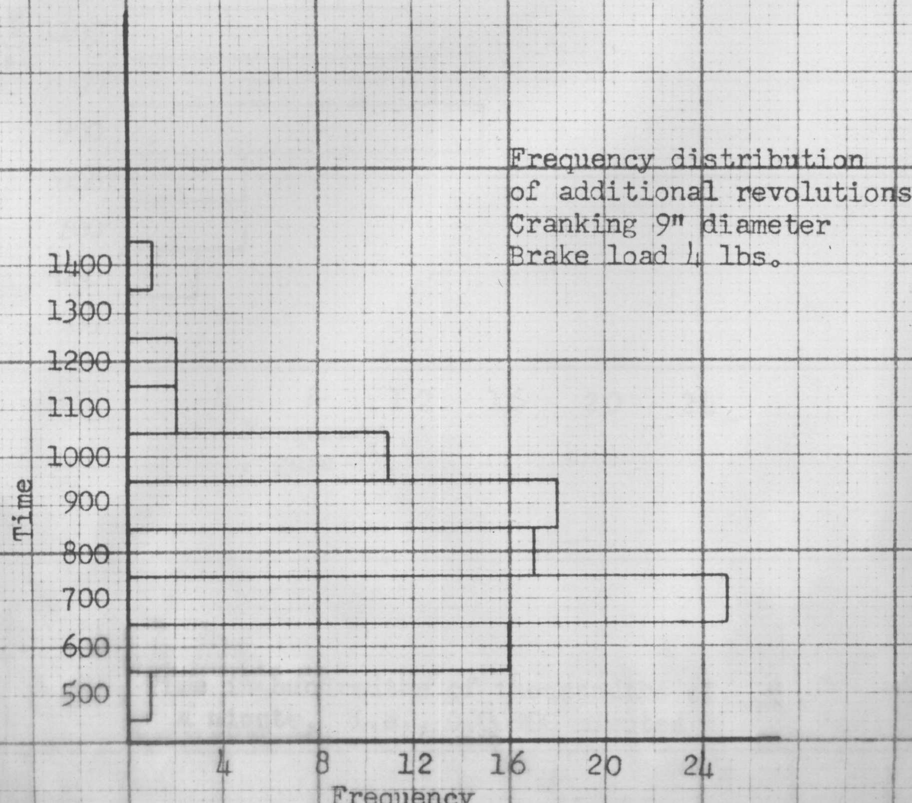


Figure 12.

Time in hundredths of thousandths of a minute, ie. 0.00700 minutes

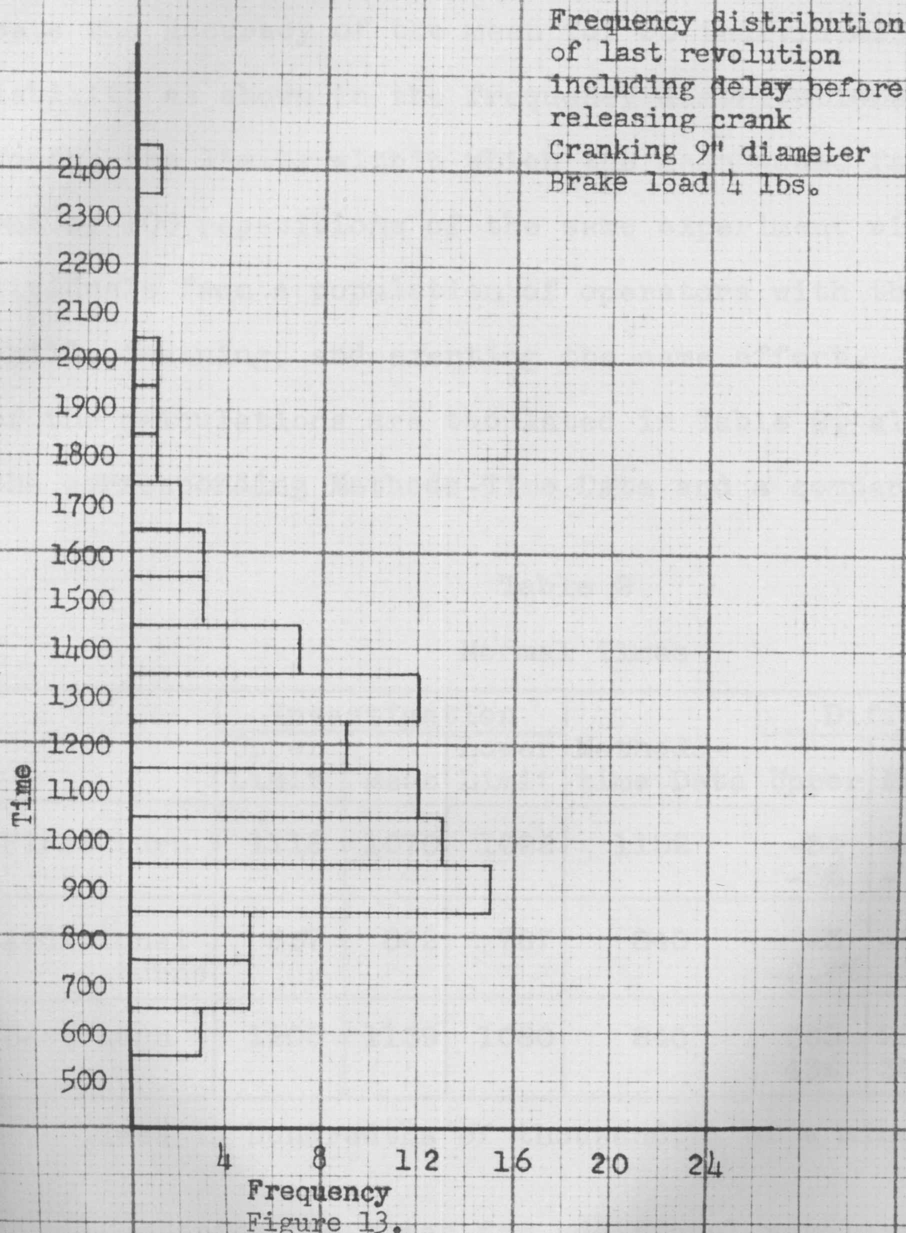


Figure 13.

Time in hundredths of thousandths of
a minute, i.e., 0.00900 minutes

A statistical analysis of the data was made to indicate the accuracy of the mean for 93 individuals with variability as shown in the frequency distributions, in other words, the limits within which the mean would fall in 95 out of 100 repetitions of the same experiment with 93 individuals from a population of operators with the same skill, training, and exerting the same effort. The results of the calculations are tabulated in Table 2, along with the corresponding Methods-Time Data and a comparison.

Table 2

Normal Times

	Investigation			Methods-time Data	Difference		
	Upper Limit	Mean	Lower Limit		Upper	Mean	Lower
First turn	1118	1070	1022	[illegible]	-34 -3%	-82 -7%	-130 -12%
Additional turns	837	802	767	840	-3 -0.4%	-38 -5%	-73 -9%
Last turn	1205	1139	1080	[illegible]	[illegible]	[illegible]	[illegible]

Times in hundredths of thousandths of a minute

Comparing the times for additional revolutions showed that the MTM standard was very close to the upper limit found in this study, althhugh it is five percent longer than the mean. Likewise, the first turn is somewhere between three and twelve percent longer, or seven percent longer than the mean. It is a possibility that the estimate of normal in this investigation was high, that the operators did actually perform at about 105% or 107% normal. Methods-time Data Tables give time values for the first and additional revolutions only. This study found the last turn to be appreciably longer than the other revolutions made after the first.

Turning a crank as in any Reach or Move motion includes acceleration and deceleration. If the crank were turned only one revolution, both acceleration and deceleration would occur in that one revolution. If the crank were turned two revolutions, acceleration would occur in the first and deceleration in the second. Preliminary investigation, Page 23, showed that the only significant difference in turns occurred in the first and last for any reasonable number of successive turns. In other words, it was shown that acceleration was completed in the first turn and deceleration did not normally begin until the last turn had started.

It might simplify calculations made in industrial practice to include both acceleration and deceleration in Standard Time for the first revolution, making it necessary then to add only an average time for each additional turn. In that case, the increment of time of the last turn over the average for additional turns, should be added to the observed times for the first turn, to give a figure that will permit calculation of time required for several turns as suggested above. This may have been the intention in the methods-time data.

Analysis of film revealed that there was an element of "Hold" involved in the last revolution. Data for the last turn was broken into actual time the crank continued in motion during the last revolution, Figure 14, and the delay previous to release, Figure 15. The "Hold" or "Delay" is the time observed between the moment the crank was decelerated to zero and the time the operator released the crank permitting the next move. The "Hold" element began with the frame where rotation from the previous frame was last apparent, to the frame just previous to the one where the fingers could be seen to have opened their grip on the crank handle.

The average time that the last revolution was in motion was 0.00982 minutes, and the average time the crank was held before Release Load was 0.00157. Thus this study indicates that the last revolution continues in motion for an appreciably longer time than other additional revolutions. The increment of the last turn in motion, without the "Hold" time, over the average for additional revolutions was 0.00180. It was 0.00142 minutes longer than the MTM stand-

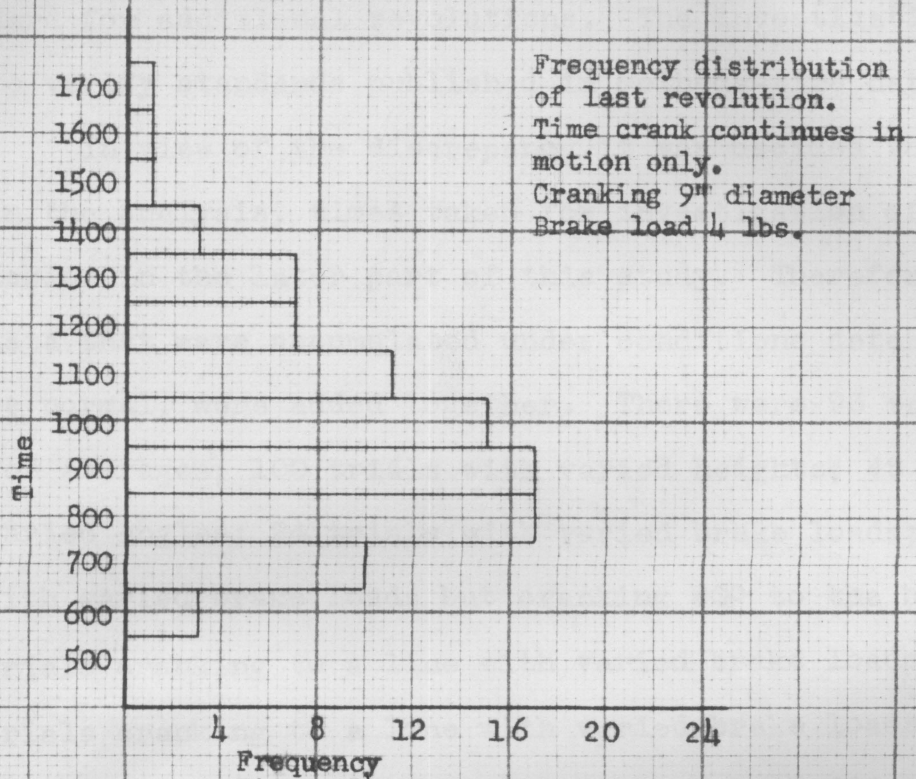


Figure 14.

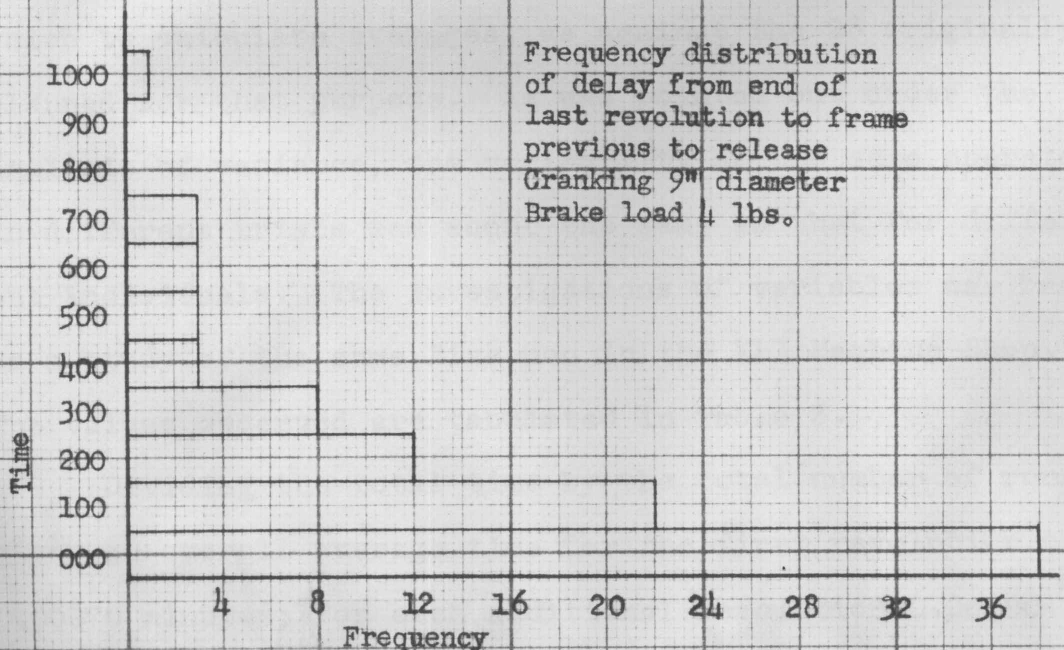


Figure 15.

Time in hundredths of thousandths of
a minute, i.e., 0.00100 minutes

dard for additional revolutions. The investigation failed to verify standards published in methods-time data.

In view of the discrepancy it was decided to include in the analysis, times taken for investigation of other variables in the later part of this study. Therefore all the data that were accumulated under conditions determined to be normal, were added together. There were 93 trials for averages; 100 trials with varied heights; 45 trials at varied angles; 24 trials with varied brake loads; 12 trials with varied brake loads but cranking 90° to the body; 30 trials cranking to a line with varied brake loads; and 24 trials cranking to a line with varied brake loads but cranking 90° to the body. This gave a total of 328 trials from which to calculate averages, as against the 93 originally planned for that purpose. As was pointed out under the analysis of variance, the variability of the same operator in different trials was about the same as that for different individuals. The investigations of variables was based on a study of the same five men in the VPI Machine Shop. The values observed are tabulated in Table 3.

Dividing the total time by the total number of runs gives an overall average time for the first revolution of 0.00970 minutes; for each additional revolution 0.00700 minutes; and for the last turn, 0.01120 minutes. If the three averages are added together, they give a total figure for a first, plus one additional revolution, plus a last turn of 0.02790 minutes. The total is very close to the figure obtained by adding a first and two additional revolutions using methods-time data, i.e. 0.02832 minutes.

Table 3.

First Revolution			Additional Revolutions			Last Revolution		
Trials	Ave. Time	Total Time	Trials	Ave. Time	Total Time	Trials	Ave. Time	Total Time
93	x 1070	= 99510	93	x 802	= 74586	93	x 1139	= 105927
100	x 928	= 92800	100	x 621	= 62100	100	x 1133	= 113300
45	x 982	= 44190	45	x 680	= 30600	45	x 1090	= 49050
24	x 987	= 23688	24	x 745	= 17880	24	x 1000	= 24000
12	x 900	= 10800	12	x 663	= 7956	12	x 925	= 11100
30	x 877	= 26310	30	x 658	= 19740	30	x 1187	= 35610
24	x 917	= 22008	24	x 702	= 16848	24	x 1187	= 28488
328		319306	328		229710	328		367475

Time values in hundredths of thousandths of a minute

The present status of time study and therefore current accumulation of standard data necessarily involves human judgement of the level of performance during the study, i.e., an individual or group conception of normal. The judgement of the writer was that the performance of the individuals used in the study was only average. This estimate was verified by other experienced time study men who observed some of the trials as they were being run.

It was not considered advisable to suggest a standard time for cranking motions based on data on one diameter only. Crank diameter is recognized as the major factor in cranking times. This study indicated that the standard time published in methods-time data should be altered , but further studies should be made on a wide range of diameters and times from the resulting curve for a tabulation applicable to specific diameters.

There may be some advantage in the field to calculate the time required for a cranking job by taking the standard time for a first turn which included an increment for a last turn and adding the product of additional turns and the standard time for each additional turn. However, it would be helpful in continued research and investigations of cranking motions to keep them separate. In fact, further investigation should be made into whether or not a single revolution of a crank would normally be made in the time calculated as just suggested. There is a possibility that if acceleration and deceleration take place in one revolution, that the time required would not be the same as the average time for a first revolution plus the increment for the deceleration of the last revolution. There might even be some doubt about only two revolutions requiring the standard time for a first revolution and a last revolution as indicated when a larger number of turns are made. This suggests further research on both questions.

5. Conclusion

(1) It was therefore concluded that further investigation should be made over a wide range of diameters establishing standard times for the first revolution; each additional revolution; and the last revolution in cranking motions. Further investigation should be made to establish times for one; two; and up to five revolutions, if they are found to be different from times for a larger number.

(2) The time required for the first revolution in cranking motions appears to be longer than published in methods-time data.

(3) The time required for the last revolution is definitely longer than for other additional turns.

(4) The standard time for additional revolutions indicated by this study for a nine inch diameter crank is shorter than the time published by methods-time data.

B. Varied Heights

Good design dictates the location of cranks as conveniently as possible to the operator. Studies have been made of the optimum location and orientation, but so far as had been observed they did not consider the average times required to perform the operation. However, the part of the machine to be adjusted, or importance of other considerations might dictate the location of a crank in a less favorable position. The height of cranks as found on equipment in common use varies appreciably. The concern of this investigation was to discover the limits between which standard time for normal conditions could be applied.

1. Operating Conditions

The important consideration is the orientation of the crank relative to the operator and it would be determined as much by the position of the operator as of the crank. Most applications of cranking are on operations where the operator is working from a standing position. Practical considerations dictate that the operator's knees establish the lower limit and the operator's shoulder the upper limit. Using an 8-3/4 inch crank, a range of 22 inches from the floor to 64 inches above the floor for the axis of the crank gives an extreme travel of the crank handle from 17½ to 68½ inches.

It was desired to hold all other conditions normal and investigate the influence of varied heights. Therefore height was varied holding the following conditions constant, 1-cranking clockwise; 2- plane of crank parallel to body; 3-no load. An investigation of the effect of brake load had not been made at this point, but many applications are geared to require very little force and free operation without any resistance other than the friction of the mechanism was decided upon. The friction of the mamachines used was so slight that the force on the crank was not measurable with the gage used.

2. <u>Subjects Studied</u>

The subjects for the investigation were five mechanics from the VPI shops. Each operator turned the crank seven revolutions, starting from rest and bringing the crank to a complete stop. This gave a first revolution, five intermediate revolutions, and a last revolution. In order to include only the time required in the "Hold" element of the last revolution to enable the operator to be sure the crank had been brought to complete rest and adjust himself for the next motion, some motivation was considered essential. Therefore a reach to the center of the crank, as though it were a tool or control button was included as part of the cycle and was performed each trial. The electric drive camera was started as the operator reached for the crank and was stopped when he had reached to the center of the crank.

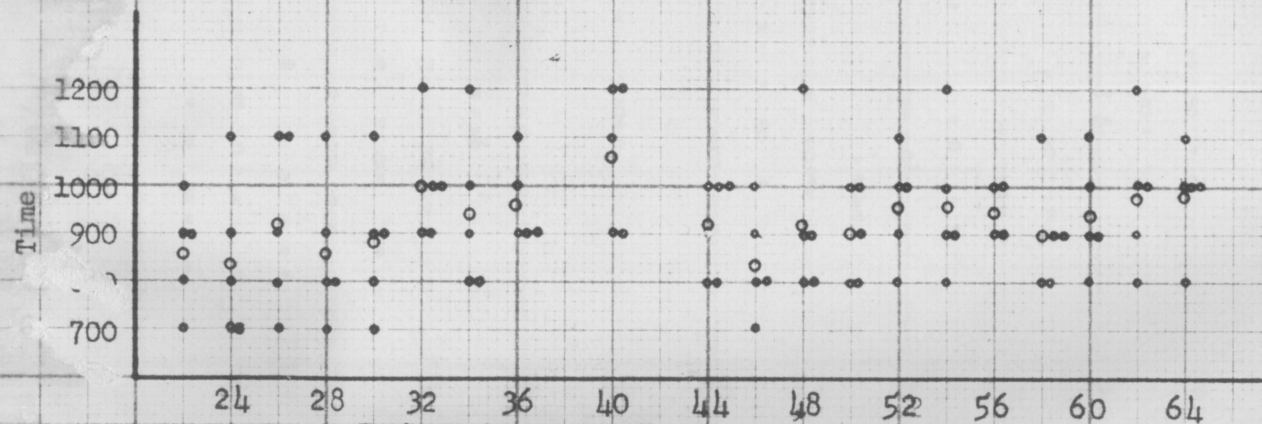
3. <u>Method of Investigation of Varied Heights</u>

The investigation of varied heights was carried out by taking motion pictures at 1000 frames per minute of five different operators, working from a standing position, turning an 8-3/4 inch crank, with no load, orientated in a plane parallel to the body of the operator. Data was collected for the time required for the first revolution, five intermediate revolutions, and for the last revolution. This was repeated for each setting of the crank from 22 inches in increments of 2 inches to 36 inches from the floor, 40 inches, and in increments of 2 inches from 44 to 64.

4. <u>Discussion of Results</u>

The times observed in this part of the investigation were plotted on Figures 16, 17, and 18. A study of the chart did not indicate any significant difference in the time required to turn the crank, as long as it was located at a point between 22 inches and 64 inches from the floor. The average for additional revolutions at all locations, was 621 hundredths of thousandths of a minute. The lowest average, 574, occurred at 50 inches. The highest average,

First revolution
Cranking 8 3/4" diameter
Varied heights from floor



Inches above the floor
Figure 16.

Time in hundredths of thousandths of a minute
i.e., 0.00900 minutes

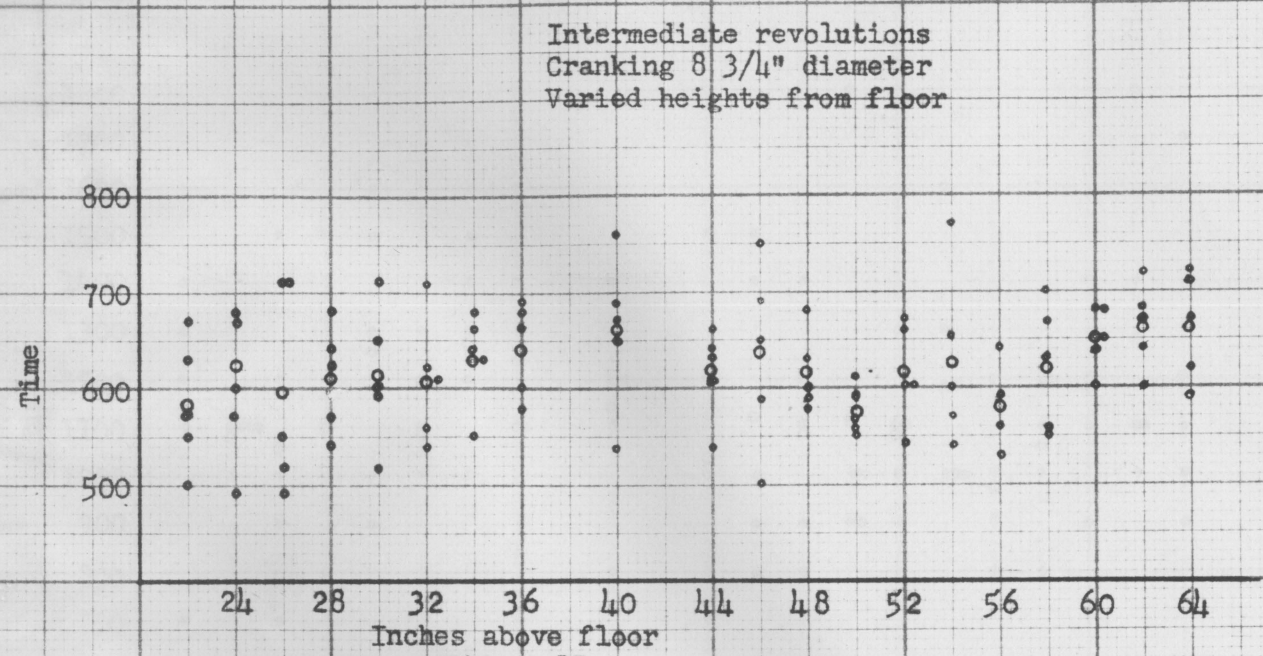
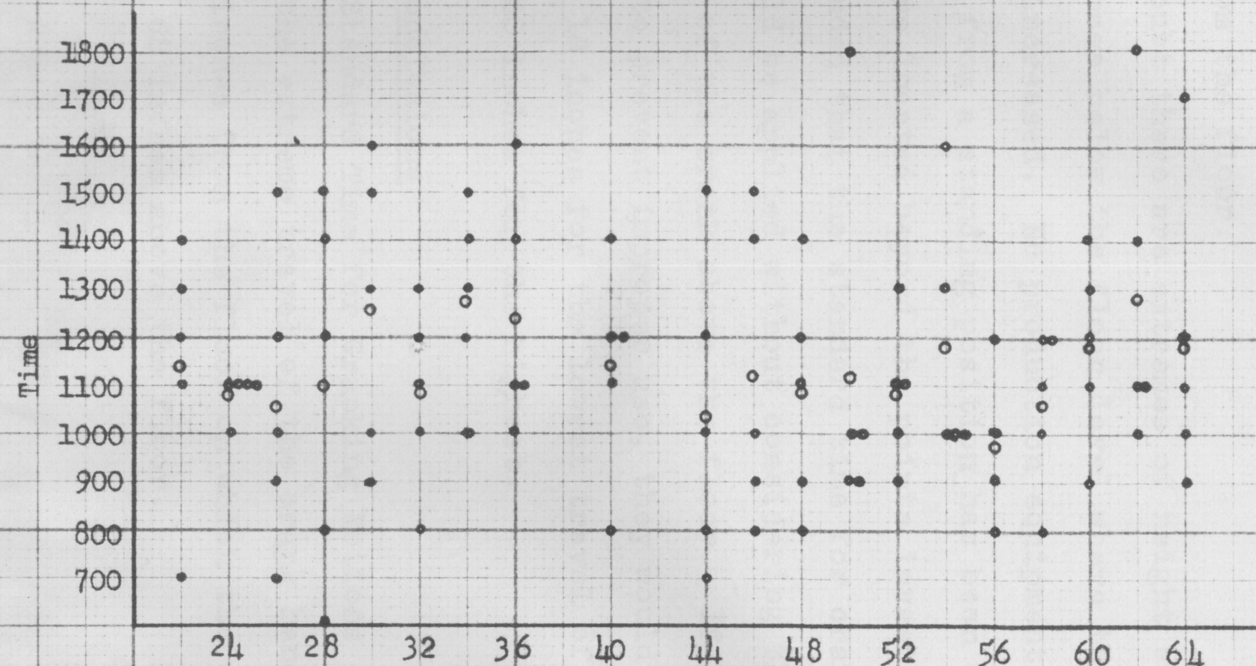


Figure 17.

Time in hundredths of thousandths of a minute
i.e., 0.00600 minutes

Last revolution
Cranking 8 3/4" diameter
Varied heights from floor



Inches above the floor
Figure 18.

Time in hundredths of thousandths of a minute
i.e., 0.01100 minutes

662 occurred at three different points, 40, 62, and 64 inches. The average times were random and gave no indication of trend. The same was true for the first and last revolutions, there was no significant trend relative to the height from the floor.

No doubt there are extremes of height above the floor and distances below the floor level where the time required would be increased. No production equipment intended for operation from a standing position has been observed where cranks were located beyond the points investigated. It was concluded that the standard time for cranking operations could be applied without considering the location or height of the crank above the floor. If limitations are required to prevent improper use, they would have to be placed at 18 inches for the lowest travel of the crank handle, and 68 inches for the highest.

5. Conclusions

The Standard Time for Cranking Motions can be applied whenever the extreme travel of the crank handle does not go below 18 inches from the floor on which the operator stands or beyond 68 inches above the floor.

C. Varied Angles

Cranks on machine tools are placed at various angles to the floor, and if the plane of the crank is perpendicular to the floor it may be orientated at various angles to the operator's body. It was decided to investigate the effect on standard time resulting from orientation at various angles to the operator's body.

1. Operating Conditions

A majority of industrial workers prefer the right hand for performing motions. For normal right hand operation, it seemed highly improbable that a designer would consider it advisable or necessary to orientate the crank other than the angles taken in a counter-clockwise direction from parallel to 90° to the operator's body. Angles taken in a clockwise direction seemed more natural for left hand operation and seldom required for the right hand, and orientating a crank beyond 90° would require an awkward reach around the crank. However, in order to observe the effect, it was decided to investigate the effect if the crank were orientated as much as 15° in a clockwise direction and operated with the right hand, and also orientating it as much as 105° in a counter-clockwise direction. It was thought that any trend could be observed by an investigation of each 15° angle in the quandrant most commonly used.

It was felt that the effect of variation in the angle of the crank would be increased at the extremes of height from the floor, that any disadvantage resulting from angular orientation would have less effect at the heights normally placed. Therefore the crank axis was located 64 inches from the floor for this investigation. No further complication in the conditions were wanted, hence the 8-3/4 inch crank was used, operating freely without any brake load.

2. Subjects Studied

The same five mechanics from the VPI shop were used as operators. Each operator turned the crank seven revolutions at each of the nine angular settings. They again started from rest, turning the crank a first, five intermediate and bringing the crank to a complete stop in the last revolution; then reaching to the center of the crank.

3. Method of Investigation of Varied Angles

The investigation of varied angles was made by a study of five operators, turning an 8-3/4 inch crank, 64 inches above the floor, with no load. Data was collected for the time required for the first revolution, five intermediate revolutions, and for the last revolution. Trials were repeated for the crank 15° in a clockwise direction parallel to the body of the operator, and each 15° in a counter-clockwise direction up to and including 105°.

4. Discussion of Results

The investigation of the effect of having the plane of the crank at varied angles to the body of the operator did not indicate a significant difference for the range studied. The average times for additional revolutions were plotted on Figure 19. The times for the first revolution and the last revolution were charted on Figure 20 and 21. The differences in time were no larger than must be expected from different trials under exactly the same conditions.

Even though trials were run at settings 15° beyond any orientation likely to be used, further rotation of the plane of the crank would in all probability result in a longer time required for turning the crank. It was felt that only the quadrant from parallel to 90° should be considered normal, but the study indicates that there is a safety factor which eliminates the possibility of a slight angle beyond the quadrant destroying the applicability of standard times in such cases.

This conclusion was verified by studies of the effect of varied brake load, and the investigation of cranking to a line. In the case of varied brake load, Figure 25, a tendency to take slightly less time for cranking when the

Each additional revolution
Cranking 8 3/4" diameter
Plane of crank at varied
angles to body of operator

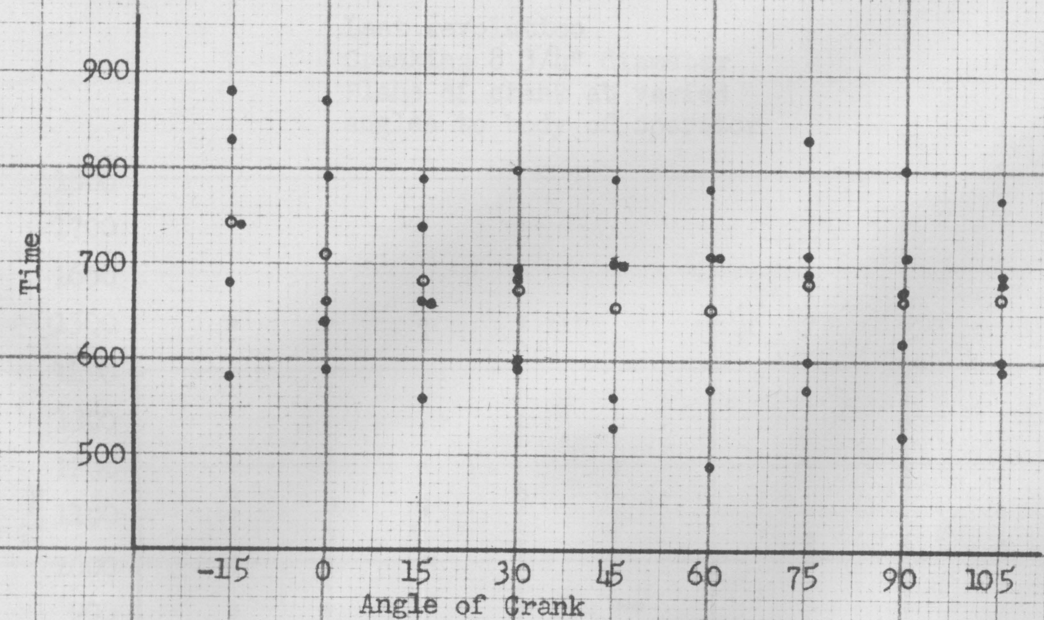


Figure 19.

Time in hundredths of thousandths of
a minute, i.e., 0.00700 minutes

First revolution
Cranking 8 3/4" diameter
Plane of crank at varied
angles to body of operator

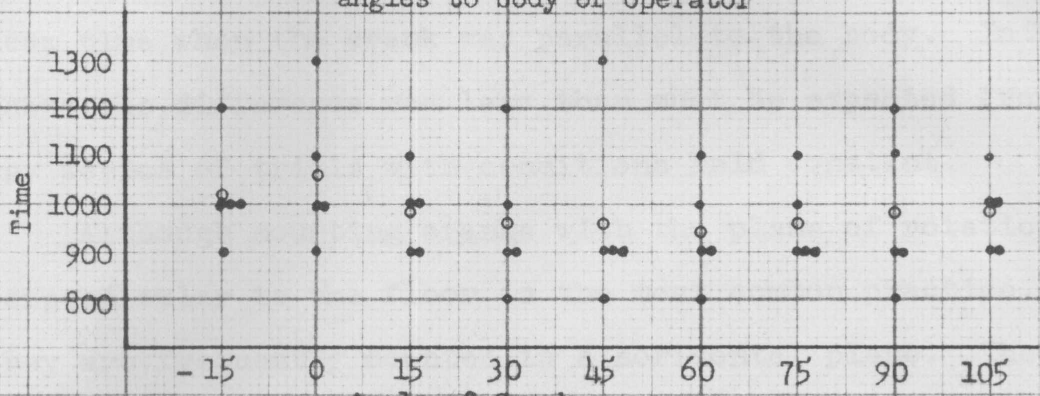


Figure 20.

Last revolution
Cranking 8 3/4" diameter
Plane of crank at varied
angles to body of operator

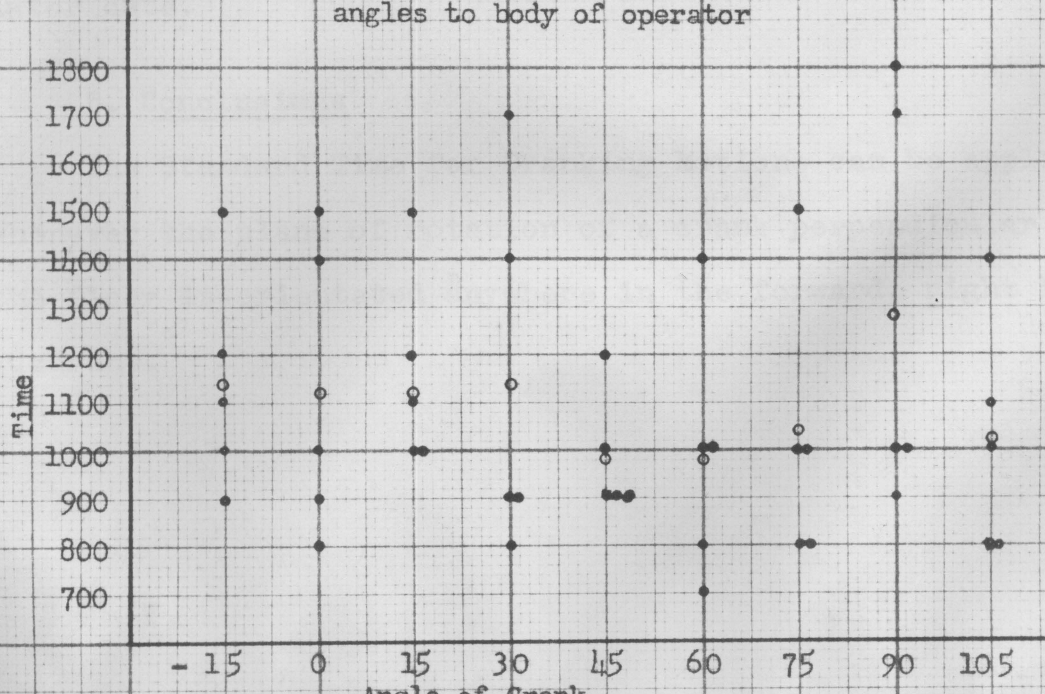


Figure 21.

Time in hundredths of thousandths of
a minute, i.e., 0.01100 minutes

crank was 90^{o} to the body was noted. In the case of cranking to a line, Figure 31, the tendency was to take slightly less time when the crank was parallel to the body. In both cases the difference was less than must be expected from any series of trials with conditions held constant.

Although mounting cranks with the plane of rotation perpendicular to the floor is the most common practice, they are frequently mounted in a horizontal plane. They are also mounted at odd angles both to the floor and to the operator's body. The effect of such variation on the time required to turn the crank should be investigated at some later date.

5. Conclusions

The Standard Time for Cranking Motions can be applied whenever the plane of rotation of a crank perpendicular to the floor is orientated anywhere in the forward, right hand quadrant.

D. Varied Brake Loads

John David Reed in his Factors Influencing Rotary Performance[2] found that the braking force was one of the factors showing the greatest effect. This can be readily accepted. His investigation made a study of maximum performance only, and did not give times that could be compared with methods-time data. Progressive industry concentrates on developing methods and equipment that require the least effort on the part of workers, and would tend to increase the diameter of a crank in order to keep the force required low. It is therefore important to know when reduced effort reduces the time required for cranking, and how much it is reduced in order to balance that advantage against the disadvantage of a longer time resulting from an increased diameter.

1. Operating conditions

In the investigation of Normal Times it was assumed that a four pound force required to turn the crank could be accepted as a normal condition. Many applications require very little effort and it seemed impractical to anticipate an extremely heavy loading for efficient hand operation. It was also thought that a unit increment in the brake load would have a more significant effect between light loadings than at heavier loads. It was decided to investigate the time required to turn the crank when running free, with brake loads of 1, 2, 3, 4, 5, and 6 pounds and with 8 and 10 pounds. The braking load was adjusted as discussed on Page 12 and illustrated in Figure 8, and the force required on the crank handle was measured with a Push Pull Gage as discussed on Page 19 and illustrated in Figure 9. This method lends itself to measurements of a particular work situation better than does the calculation of brake load in foot pounds. An ordinary spring scale or a Push Pull Gage is usually available in any plant. When running free, the force that was required on the crank handle to overcome the friction of the mechanism could not be measured accurately with the gage used. The force was approximately one quarter pound or less.

It seemed possible that brake load might effect cranking motions parallel to the operator's body more than with the plane of the crank perpendicular to the body. In the latter case the muscles of the upper arm might be used more effectively. Even though an earlier investigation indicated the angle at which the crank was orientated had no effect on the average time for cranking motions under normal conditions, it was felt worth while to investigate the possibility that it might under certain brake load conditions.

The axis of the crank in this investigation was held at a normal height from the floor. Waist high was considered normal, and 36 inches was selected as the height to be used. The diameter of the crank was 8-3/4 inches, again one of the commonly used sizes.

2. Subjects Studied

Four operators were studied cranking parallel and two turning the crank in a plane perpendicular to the body. The usual method of starting from rest, making a first, five intermediate turns, and a last revolution, followed by a reach, was the cycle for this study.

3. Method of Investigation of Varied Brake Loads

The investigation of the effect of varied brake loads was made by a study of four operators, turnihg an 8-3/4 inch crank, 36 inches above the floor, and orientated in a plane parallel to the operator's body. Another series of trials on two operators was made under the same conditions except with the crank orientated in a plane 90° to the operator's body. Data was collected on the time required when the crank was turned with zero brake load; from one pound, in increments of one pound, up to and including six pounds; and at eight and ten pounds.

4. Discussion of Results

The times observed for cranking parallel to the body were plotted on Figures 22, 23, and 24. The average times

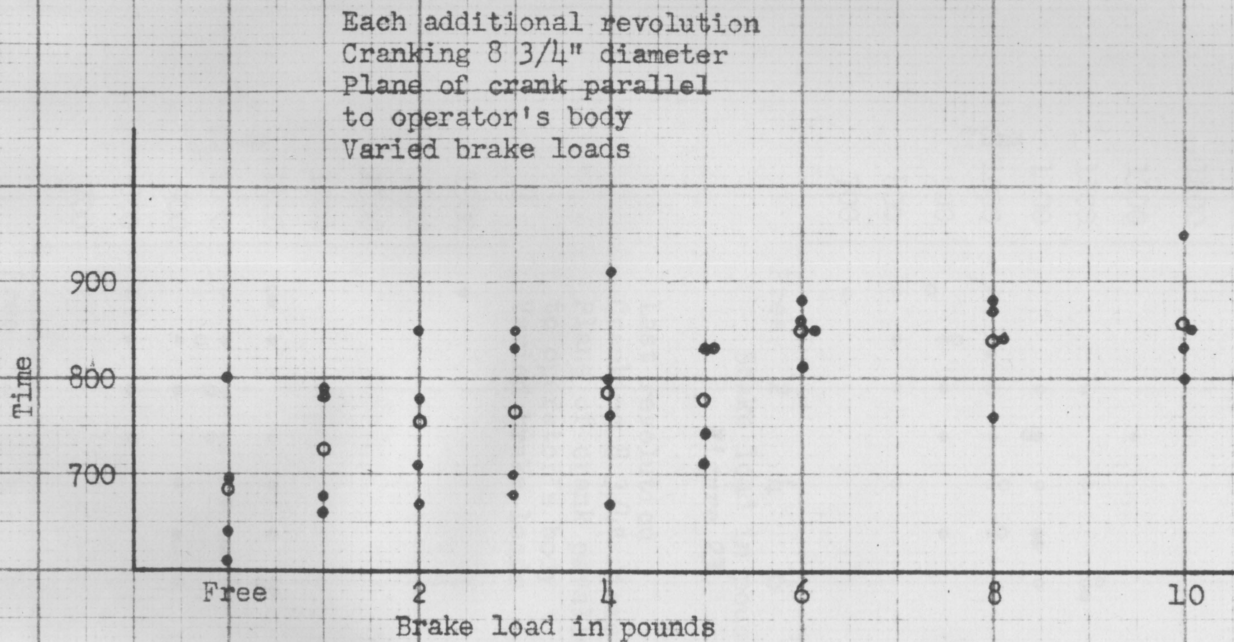


Figure 22.

Time in hundredths of thousandths of a minute
i.e., 0.00800 minutes

First revolution
Cranking 8 3/4" diameter
Plane of crank parallel
to operator's body
Varied brake loads

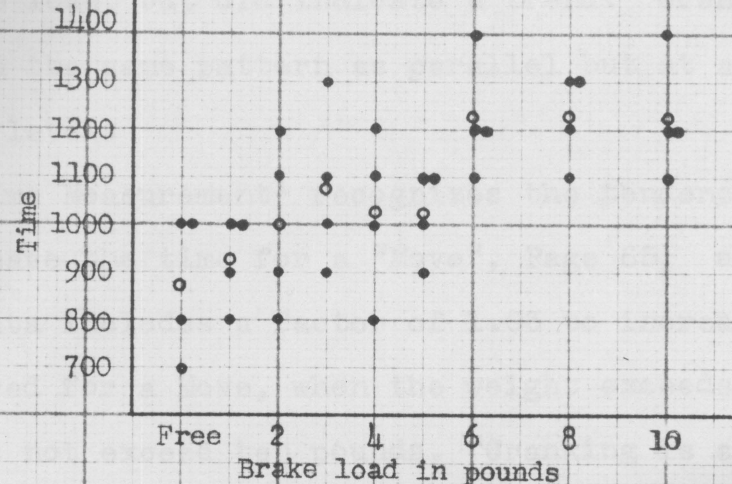


Figure 23.

Last revolution
Cranking 8 3/4" diameter
Plane of crank parallel
to operator's body
Varied brake loads

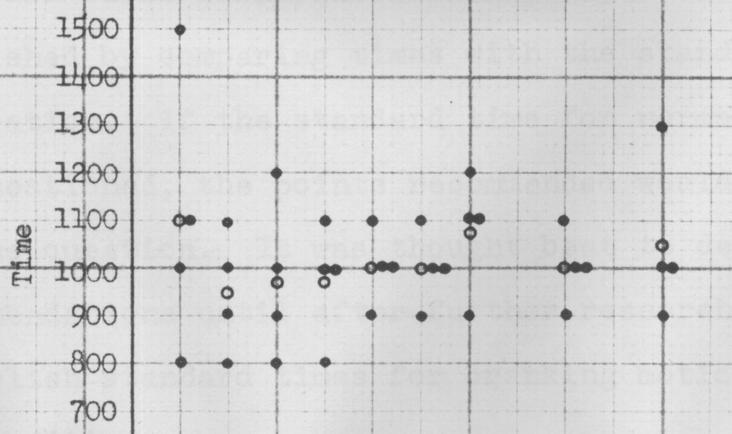


Figure 24.

Time in hundredths of thousandths of
a minute, i.e., 0.01000 minutes

for cranking 90^{o} to the body were plotted on Figure 25, along with the average times for cranking parallel. The data shows only a slight tendency for slower times with increased brake load, but did indicate a trend. Cranking at 90^{o} followed the same pattern as parallel but at a slightly lower level.

Methods-Time Measurement[1] recognizes the tendency for weight to increase the time for a "Move", Page 65, and methods-time data includes a factor of 1.03 to increase the time required for a Move, when the weight exceeds five pounds but does not exceed ten pounds. Cranking is a variation of Move and possibly should be treated in a similar way.

The factor for increased brake loads, and the point at which it should first be applied to cranking motions, must be established by comparing times with the standard for normal operation. If the standard time for normal operation is questioned, the points recommended would be open to the same question. It was thought best to delay definite recommendations until after further research designed to establish standard times for cranking motions under normal conditions.

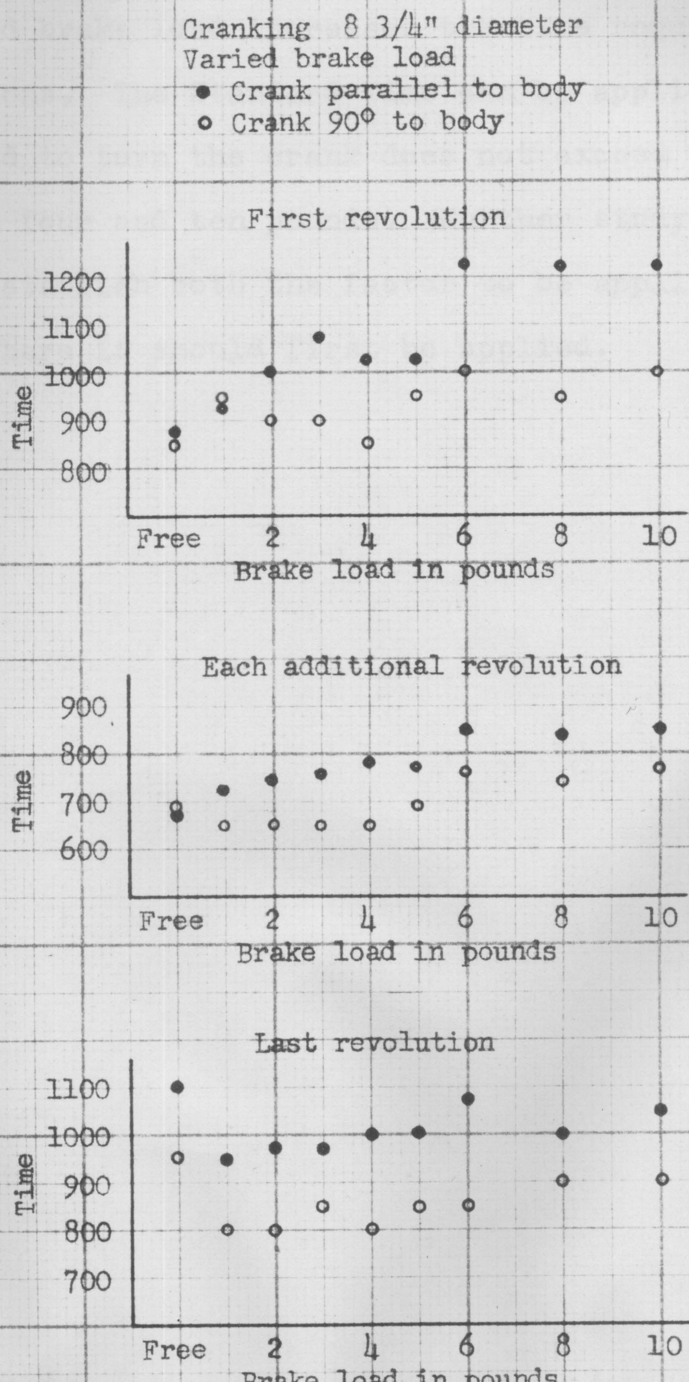


Figure 25.

Time in hundredths of thousandths of a minute, i.e., 0.00900 minutes

5. Conclusions

Increased brake load increases the time required for cranking motions. The Standard Time can be applied if the force required to turn the crank does not exceed some value lying between four and ten pounds. Further study will be required to establish both the factor to be applied and the exact point where it should first be applied.

E. Varied Brake Loads to a Line

An investigation of the effect of Cranking to a Line was made. It was felt that there might be a tendency to decelerate for several turns as the operator approached the line, or that conscious effort to prevent going beyond the line might require a longer time for the last turn. Also, the effect of approaching a line might vary with the resistance to the turning effort.

1. Operating Conditions

The investigation did not take into account extremely accurate adjustment to a line or dimension. The apparatus is described on Pages 12 and 19 with an illustration in Figure 10, Page 20. The width of line to which the pointer was turned required that the crank come to complete rest with-in a quarter of a revolution. The line was located in a different place for each trial. It therefore required visual and muscular coordination to bring the crank to rest with the pointer on the line, as against memorizing some point of angular rotation to locate the line. The operator was required to turn the pointer to the line and was not permitted to reverse direction and bring it back in case the pointer passed the line. Failure to stop the crank with-in a quarter of a turn, either did not bring the pointer up to the line or carried it past.

This cannot be considered accurate work, but anything more accurate would soon demand a stop watch study of the particular degree of accuracy, or extensive data to establish average skill for each degree of accuracy. The accuracy used in the investigation was considered sufficient to indicate the effect to be expected.

As was indicated earlier, the effect of approaching a line might be different at different brake loads. In order to study the relationship, trials were made at each loading from zero, in increments of one pound up to and including six pounds, and also at eight and ten pounds.

A probability that cranking to a line, as well as the effect of increased brake load, might be different when the plane of the crank was orientated at different angles was considered. Trials were made with the crank parallel to the body and 90° to the body to bring out that point.

Other conditions were maintained normal, using the 8-3/4 inch diameter crank, located 36 inches from the floor.

2. Subjects Studied

The five mechanics from the VPI shops each made a run with each brake load setting, one run with the crank parallel to the body, and one run with it 90° to the body.

3. Method of Study of Varied Brake Loads to a Line

The investigation of cranking to a line was made by a study of five operators, turning an 8-3/4 inch crank, 36 inches above the floor, and orientated in a plane parallel to the operator's body. A study was made of nine different brake loadings, varying from zero to ten pounds.

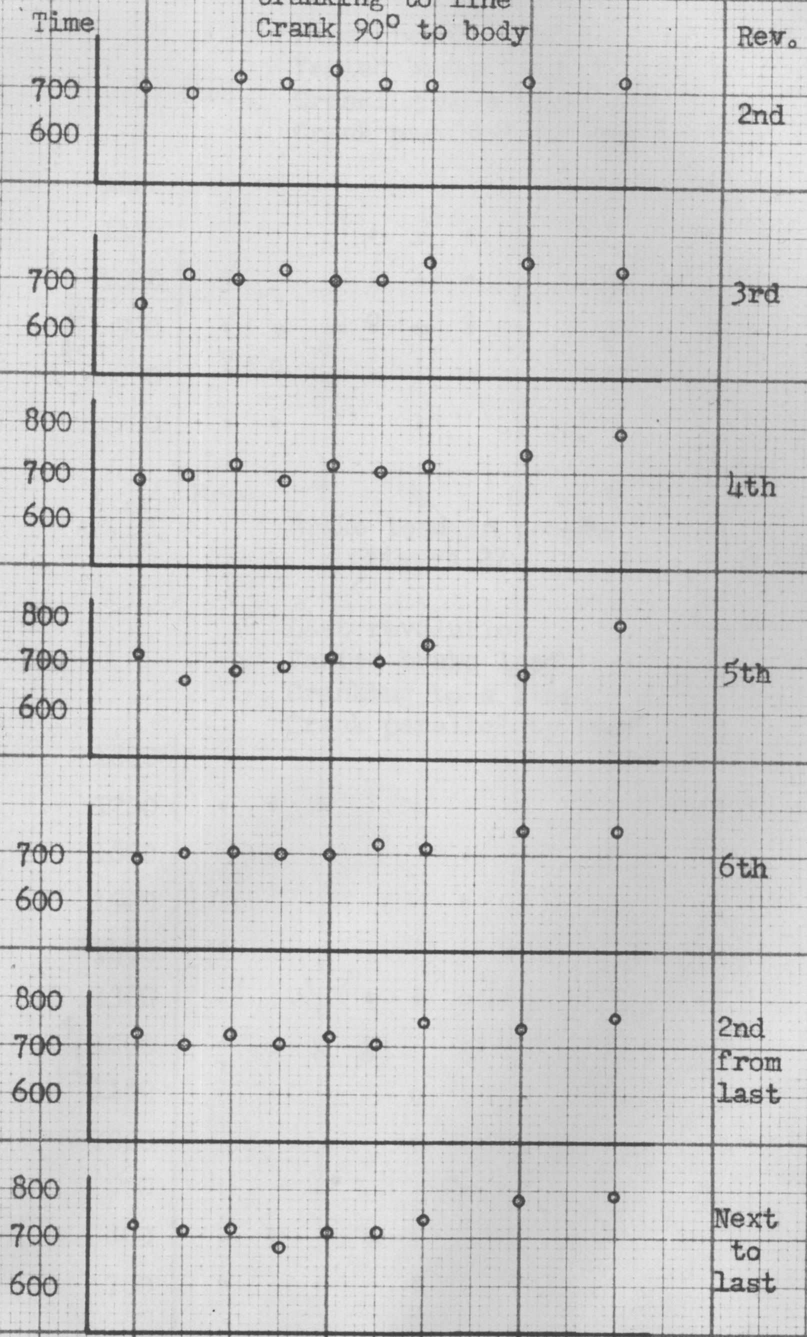
Cranking to a line was also studied with the same five operators, turning an 8-3/4 inch crank, 36 inches from the floor, but orientated at 90° to the operator's body. The same nine brake loadings were included.

Analysis of each additional revolution was desired in this case to disclose any tendency to decelerate over several turns as the pointer approached the line. In order to get a more composite picture of the data, and analyze the effect on each revolution, only the averages of the five operators were plotted for each intermediate turn. All readings and averages were plotted for the first and last turn.

4. Discussion of Results

The data collected for cranking to a line with the crank parallel to the body was plotted on Figures 26, 27, and 28. There was no significant trend or difference in the time required for any of the intermediate turns. The same pattern prevailed for each of the loadings resisting rotation. There was no significant change in the average times for the first turn, additional turns, or the last

Additional revolutions
Varied brake load
Cranking to line
Crank 90° to body



Brake load in pounds
Figure 26.

Time in hundredths of thousandths of a minute, i.e., 0.00700 minutes

First revolution
Varied brake load
Cranking to a line
Crank parallel to body

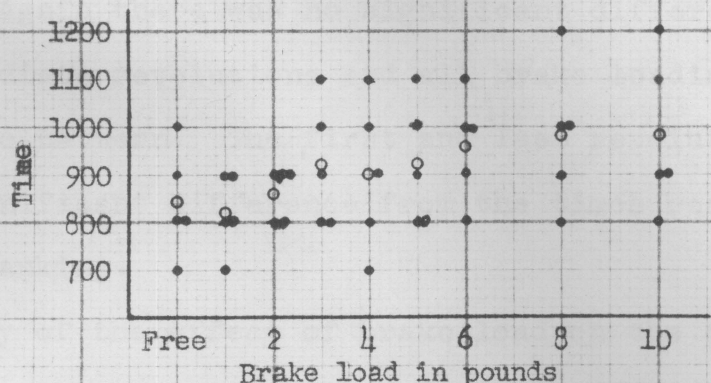


Figure 27.

Last revolution
Varied brake load
Cranking to a line
Crank parallel to body

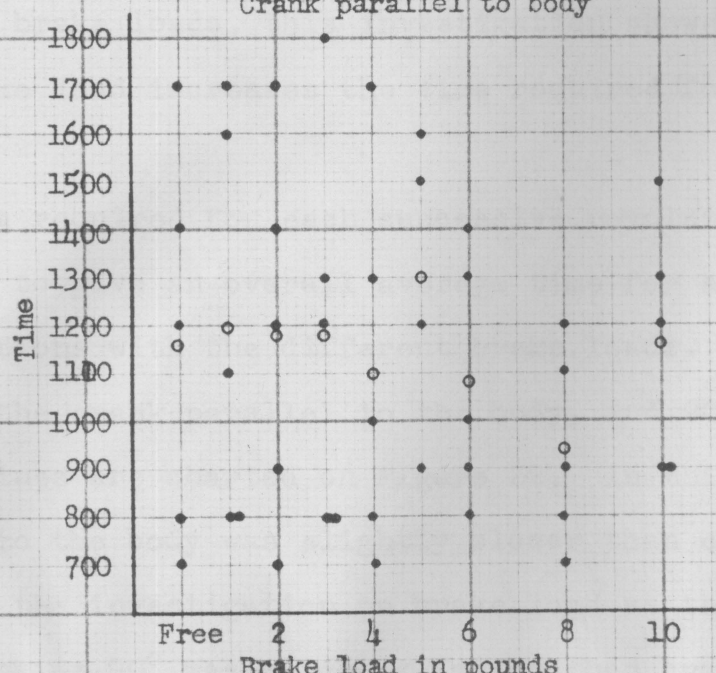


Figure 28.

Time in hundredths of thousandths of
a minute, i.e., 0.01200 minutes

turn from the time required for other normal conditions.

The data for cranking to a line with the crank orientated 90° to the operator's body was charted on Figure 29, 30, and 31. Again there was no significant difference between intermediate revolutions and all brake loadings followed the same pattern. The first and last revolutions showed no significant difference from the times required for normal cranking.

The study of the effect of brake load on the time required when cranking to a line resulted in additional data relative to the effect of varied brake loads. As in the case of the investigation designed specifically to analyze the effect of brake loads, this investigation showed that increased brake load increases the time required for cranking motions.

The times required for each successive revolution were averaged to give an overall average time for additional revolutions with the different brake loads. This was done for the crank parallel to the body, and 90° to the body. The values are charted on Figure 32. In this case cranking 90° to the body was slightly slower than cranking parallel. In the investigation on brake load as the only variable, cranking 90° was slightly faster than cranking parallel. In neither case is the difference significant, and being in opposite directions verifies the conclusion

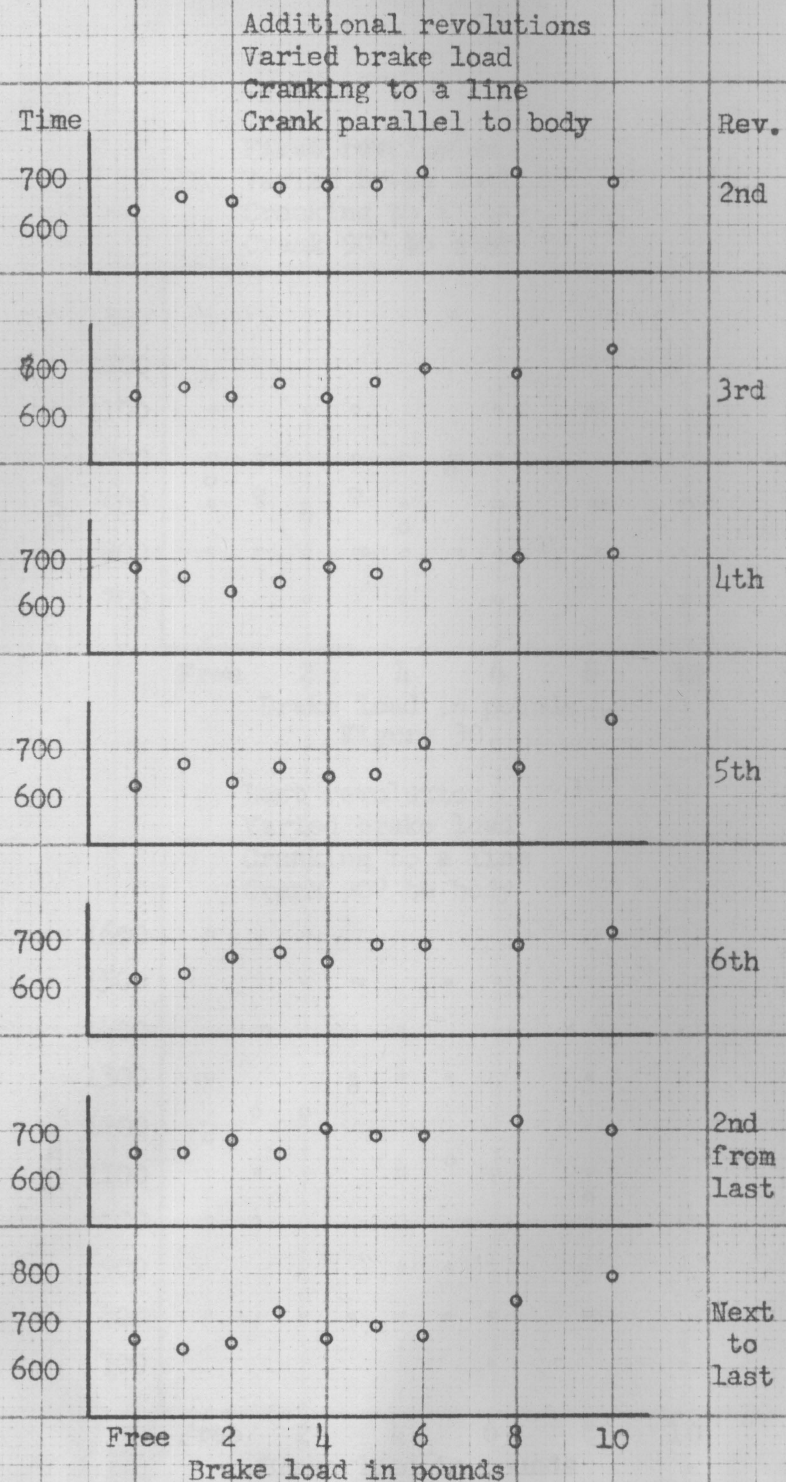


Figure 29.

Time in hundredths of thousandths of a minute, i.e., 0.00700 minutes

First revolution
Varied brake load
Cranking to a line
Crank 90° to body

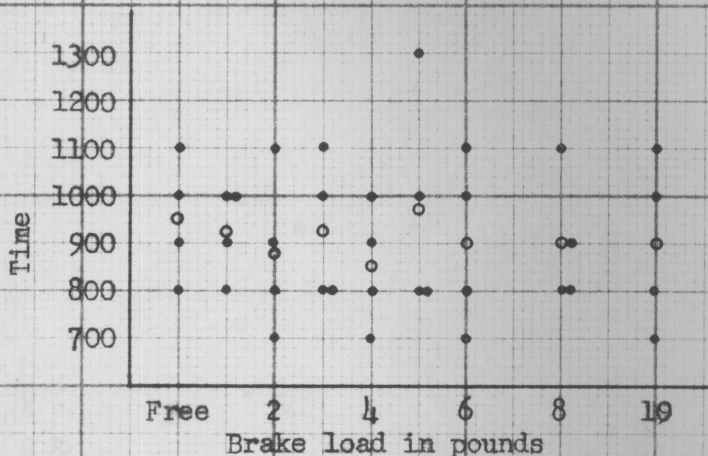


Figure 30.

Last revolution
Varied brake load
Cranking to a line
Crank 90° to body

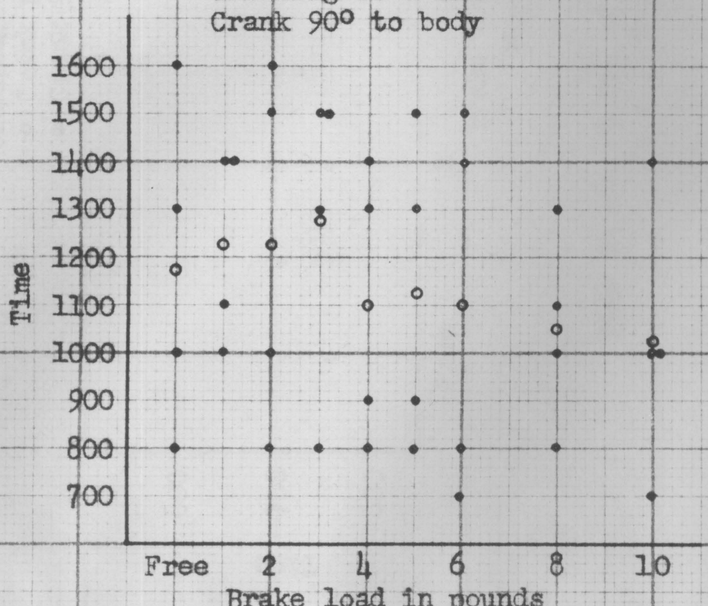


Figure 31.

Time in hundredths of thousandths of a minute, i.e., 0.01100 minutes

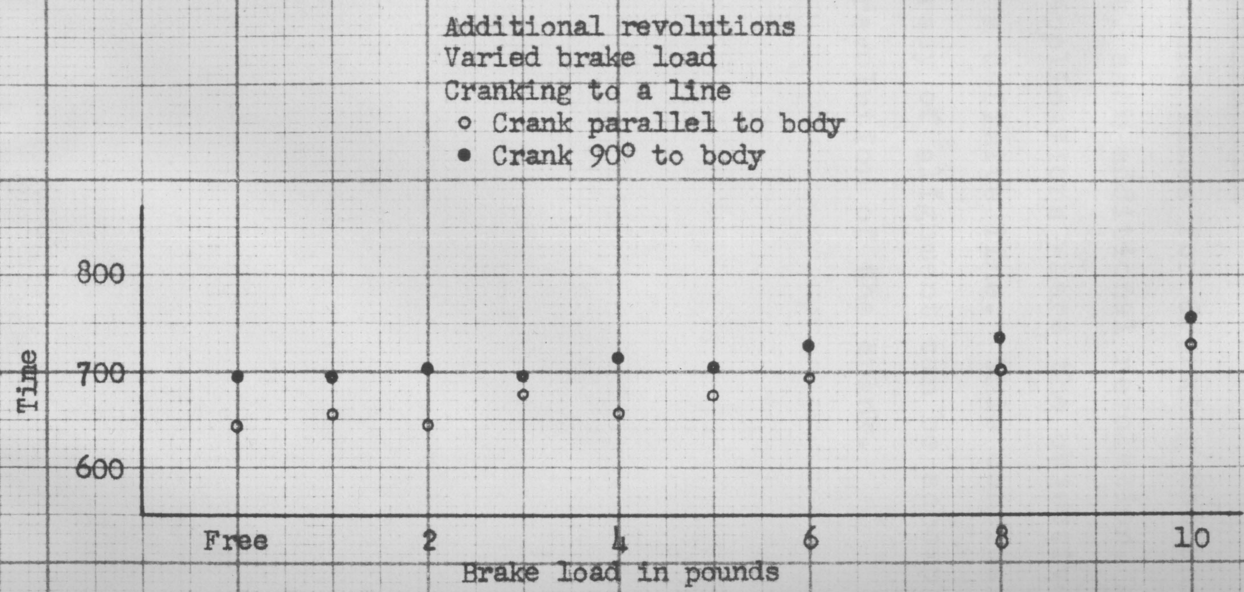


Figure 32.

Time in hundredths of thousandths of a minute
i.e., 0.00700 minutes

that orientation in the forward, right hand quadrant, has no effect on the time required for cranking motions.

5. Conclusions

Standard Times for Cranking Motions can be applied for the first, each additional revolution, and the last revolution in applications where the objective is to adjust some point to a definite line. This conclusion holds provided the accuracy of alignment can be accomplished within a quarter revolution of the crank.

V
CONCLUSIONS

The conclusions drawn from this investigation were -

1. Further investigation should be made over a wide range of diameters to establish standard times for the first revolution; each additional revolution; and the last revolution; in cranking motions.

2. The time required for the first revolution in cranking motions appears to be shorter than the published methods-time data.

3. The time required for the last revolution is definitely longer than for other additional turns. Existing methods-time data does not differentiate the last turn from other additional revolutions.

4. The standard time for additional revolutions indicated by this study for a nine inch diameter crank is shorter than the published methods-time data.

5. The Standard Times found in this investigation for Cranking Motions should be limited to applications where -

a. The crank handle does not reach a point lower than 18 inches from the floor on which the operator stands.

b. The crank handle does not reach a point higher than 68 inches above the floor on which the operator stands.

c. The crank mounted on a horizontal axis and to be operated with the right hand is operated in a plane parallel to the operator's body or orientated in the forward, right hand quadrant.

d. The force required to turn the crank does not exceed a definite number of pounds. This study indicates the point should be somewhere between four and ten pounds. The limiting force could be readily established in relation to the average time found in this study, or to the standard published in methods-time data. The point should be determined by the relationship with the average, and therefore should be finally established by comparison with the finally accepted standard time.

e. Standard Times are applicable to cranking motions when the objective is to bring some point into alignment, provided the accuracy of alignment is satisfactory if accomplished within a quarter revolution of the crank. The accuracy of alignment would vary with the ratio between the crank rotation and movement of the point controlled. This study only investigated an accuracy requiring stopping the crank within a quarter turn and found cranking to a line could be done in the average time for average conditions.

VI
SUMMARY

As was discussed in the Introduction to this thesis, Page 5, Industry needs a generally accepted standard measure that can be applied directly to the motions used in performing a task. Only by uncovering differences in experience, finding the fundamental reasons for the differences, and establishing a means of bringing them into agreement, can the objective be realized. Disagreement in the measurement of a variable is in no way discouraging. The collection of data from a wide range of sources and investigations will result in the best average and acceptable standard for universal use.

Further investigation to establish times for cranking motions over the practical range of crank diameters and coordination with industry in the area has been planned. Establishing the next most important factor, that of brake load, limiting the application of normal times, will then be a relatively short step, as will establishing an increment factor for increased resistance to rotation.

There is some question as to whether the conclusion made in the preliminary investigation, to the effect that only the first and last turn differed significantly from other turns, would hold if a lesser number of complete revolutions were made. Additional studies should be made to investigate the probability of only one, two, three, or four turns in addition to the first and last, requiring the same average time this investigation found to be the same for all additional turns of five or more. The probability of making only two turns in the time required for a first turn plus a last turn should also be investigated. Another study is required to establish a time for one single revolution, where both acceleration and deceleration occur in the same revolution. It may be that a single turn would usually be accomplished in the time for a first turn plus the differential between the last turn and other additional turns, but a study is required to establish the validity of such a deduction.

This investigation seemed conclusive in establishing a broad latitude for height of crank from the floor, angle of crank, and controlled stopping point. It is hoped that any disagreement of other investigators or observed in practice will be reported to permit prompt investigation of the factors discovered.

VII
ACKNOWLEDGMENTS

The author wishes to express his appreciation to Professor Herbert L. Manning, Head of the Industrial Engineering Department, Virginia Polytechnic Institute, for his advice and criticism throughout the investigation and the writing of this thesis.

The assistance of in designing the apparatus and his supervision of the construction was indispensable to the investigation. His entire organization,

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, cooperated far beyond the call of duty. Their constructive suggestions all along the way and conscientious efforts to perform the tasks studied in strict accordance with the conditions imposed, cannot be exaggerated.

The Industrial Engineering staff and student body assisted in procuring data representative of a normal average, and their willing cooperation is highly valued.

The advice and guidance of the members of the staff of the Department of Statistics at Virginia Polytechnic Institute, Dr. Boyd Harshbarger, Dr. Ralph A. Bradley, Dr. David B. Duncan, and Dr. Milton E. Terry II, in making the analysis of variance is fully appreciated.

VIII
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