AN INVESTIGATION OF THE ELECTRIC POWER SITUATION AT THE KNOXVILLE COTTON MILLS.

By

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Introduction.

This thesis is the result on an investigation made into the electric power situation at the plant of the Knoxville Cotton Mills. The investigation was undertaken to determine whether any changes might be made in the method of handling the power equipment, which would result in decreasing the cost of operation.

The officials of the mill, as well as the engineer, co-operated to the fullest extent while these tests were being made. A great deal of assistance in the way of suggestions and criticisms was given by Dr. Perkins. R.L.Harvey and J.B.White were indispensable in the actual work at the plant and a number of the employees of the Knoxville Power & Light Company were glad to furnish data and explanations of their billing and contracts whenever they were called upon. All of this assistance was very gratefully received, and is hereby acknowledged.

Statement of Purpose.

As has been stated, this work was undertaken with the chief idea in mind that the results might point to greater economy of operation of the plant. The loads carried by many of the motors had been increased or decreased since their original installation and it was thought that they might excessively overloaded, with consequent overheating, or else greatly underloaded, with the corresponding low power-factors and low efficiency. It was also thought that the maximum demand might vary over wide limits, with possible high peaks when starting up in the morning, and after the noon hour. Any of these factors might easily cause an excessively high bill, while the correction of such conditions would be a comparatively simple matter.

A copy of the power contract under which the power for the Knoxville Cotton Mills is purchased from the Knoxville Power and Light Company is shown in figure 1. It will be noted that there are clauses covering each of the phases mentioned.

Filed with the Railroad and Public Utilities Commission of Tennessee, November 12, 1927. Effective on all bills rendered on and after December 1, 1927, Superceding Rate H, effective April 1, 1925 - Tendency of Rate downward.

KNOXVILLE POWER & LIGHT COMPANY

Knoxville, Tennessee

ELECTRIC SERVICE - SCHEDULE No. 3

RATE H-1

LARGE ALTERNATING CURRENT POWER SERVICE - THREE PHASE

AVAILABILITY:

This rate is applicable for service to alternating current power installations located on the existing three phase distribution lines of the Company and contracting for not less than 25 KW.

NET RATE:

$100.00 net each month for the first 25 Contract KW, or less
2.00 net each month per KW for the next 25 Contract KW
1.25 net each month per KW for each KW in excess of 50 Contract KW
0.85c net per KWH for all energy used per month.

GROSS RATE:

The gross rate is the above stated net rate plus one (1) mill per KWH on all energy used during the month.

CONTRACT KW:

The contract KW will be taken as the average KW supplied during the three 15 minute intervals of maximum use occuring on three separate days in any one month of the twelve months ended with the current month. In no event will the Contract KW be taken at less than 25 KW, nor less than 40% of the connected load.

POWER FACTOR:

The rate schedule above is made on the basis of the customer taking and using electric power and energy in such manner as will maintain an average power factor at the point of measurement as nearly 100% as practicable. In the event, however, that the customer's power factor shall average less than 100% lead or lag, during any month, then the Company may adjust the Contract KW for billing purposes as follows:

For average power factor of less than 100% but not less than 80%, no adjustment shall be made.

For average power factor of less than 80%, the KW supplied during the three 15 minutes intervals of maximum use during the month will be adjusted to the equivalent of an 80% power factor by multiplying by 80 and dividing by the power factor actually established, and such adjusted demand shall be used in the determination of the Contract KW.

PAYMENT:

Bills will be rendered at the net (discounted) rate and are due and payable within ten (10) days from the the date thereof. When not so paid the gross rate applies.

CONTRACT PERIOD:

This rate applies to service for a period of not less than five (5) years, but contracts for shorter periods may be accepted by the Company when circumstances justify.

Figure 1.

Description of the Method and Apparatus Used.

A test such as was made for this study would naturally be less exhaustive than a laboratory test. In the first place, the motors could not be stopped for any long period, as it was necessary to keep the machines at work. Then, too, the motors were usually mounted at some more or less inaccessible point, the ceiling in most cases, thus complicating matters still more.

The principal information sought for was rated horse-power and speed (from the nameplate), together with input power, power-factor, and actual speed, both at full load and friction load. In some cases the motor was so located that the speed could not be taken with safety, so the other observations, only, were made. The friction load was the load with all belts running on the idler pulleys of the various machines. If this value were too great a proportion of the load, it would naturally be one cause of a high power bill.

As the instruments had to be carried about over the plant to the various motor locations, they were necessarily portable and as light as possible. All the motors operate of 3 phase, 60 cycle alternating current at 220 volts. Thus the measurements could be made with one voltmeter, one ammeter, and one wattmeter, the three instruments being mounted firmly on a folding table. Four leads, of flexible lamp cord, about twenty five feet in length, were taken from the table. Two of these were connected to the voltmeter and the potential coil of the wattmeter, in parallel. The other two were connected to the ammeter and the current coil of the wattmeter, in series. This lead was provided with a small knife switch to short-circuit the instruments when starting up the motors, to prevent excessive current from flowing thru the instruments. The current was supplied by a current transformer having 120 turns on the secondary. This instrument was originally designed to be placed on a bus-bar which acted as a one turn secondary, thus giving a ratio of 120:1. However, as the motors to be tested were of a wide range of sizes, a variable transformer was necessary. To accomplish this variation, a length of about twenty five feet of number 0000 stranded wire was provided, with lugs soldered to the ends. This wire could be passed thru the center of the core a number of times, so that the ratio might be varied from the original ratio to 10:1. The surrent taken by any of the motors could be easily contained in this range, so the same instruments could be used for the entire series of tests.

The lugs on this wire were arranged to be bolted to the ends of dummy fuses, and as the various sizes of motors naturally required different types of fuses, a full set of dummies was provided. The motor would be stopped long enough to remove one of the fuses and replace it with a dummy, then the motor would be started again. The usual practice when starting up a motor was to shift the belts to the idler pulleys to reduce the starting load and eliminate belt slippage or breakage, so in this case the friction load readings were made before placing the load on. Then the machines were all started and the full load readings taken.

The potential leads were supplied with clips on the ends, one of which was placed on the leg of the circuit in which the current was being measured, and the other on each of the other two legs in turn. Thus, there were two voltmeter and two wattmeter readings for each load. The two voltages were the same, or very nearly so, but the wattmeter readings were different, as the power-factor was naturally something below unity. The sum of these two readings was the total power taken by the motor, and were both positive when the motor was loaded. This indicated a power-factor of between fifty and one hundred percent, while on friction loads it was between zero and fifty percent, as indicated by the fact that one of the watt-meter readings was negative to the other.

The connections to the instruments are shown in figure 2.

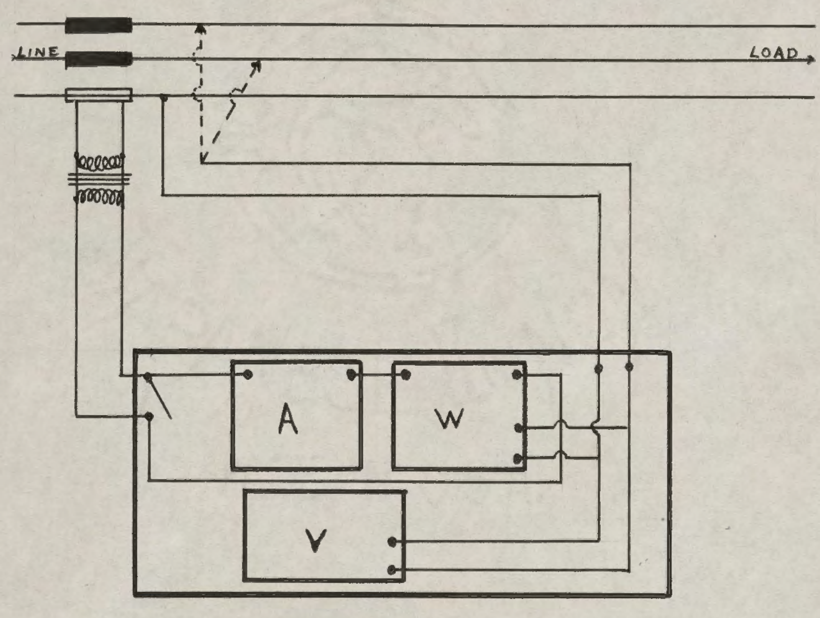


Figure 2.

The fluctuations of the meters made accurate readings difficult. The nature of most cotton mill machinery makes it tend to vary the load on the motor slightly, in a rhythmical manner. Also, on the friction loads, where they were small as compared to the size of the motor, there was a tendency to hunt, giving a similar swing to the needles of the meters. To eliminate this source of error, the three meters were read simultaneously, and for the two readings of each load the wattmeter was read at the mean between the extreme points of the swing of the needle. An additional check of the accuracy of the observations was obtained by calculating the value of cosine theta from the two wattmeter readings, as will be explained later, and with this value checking the readings of the other two instruments. In some few cases the discrepancies were so large that it was necessary to get new values. By careful work, it was possible to secure values that were very accurate.

Before starting the tests, all meters were calibrated against known standards. Direct current was used, but it was reversed in direction for each point read, in order to allow for any errors due to directional effect. Thus a true calibration for alternating current was secured.

The standard for calibration was the Weston Standard Laboratory Voltmeter, in the electrical laboratory. This instrument had been previously checked for error thru the use of a potentiometer and standard cell. This standard cell in turn had been checked against another standard cell, which had been borrowed from the physics department, and it in turn had been checked against a new and carefully guarded cell in the same department, which was accepted as standard. All this work was done by the writer, tho the calibration of the voltmeter by means of the various standard cells had been done at a previous time.

Such specious accuracy would not be necessary for the purposes of this thesis, as other errors might more than compensate for such corrections. However, as these corrections were available, it was thought well to make use of them.

The voltmeter used for these tests, a General Electric Co., instrument, serial number 510,644, was checked directly against the standard voltmeter. As the voltage from the direct current generator in the laboratory was inclined to fluctuate, a high voltage storage battery of the radio "B" type was used as a source of potential. Its value was varied by means of a potentiometer, this being adjusted to give a desired reading of the standard instrument, then the readings of the alternating current instrument, both forward and reversed, were noted. Table number II in the appendix shows these values, with the reading of the standard voltmeter corrected by means of the calibration curve, figure 3, also in the appendix. A curve drawn from the figures of table II is shown in figure 4.

A Weston alternating current ammeter, serial number 39,762, was calibrated against the same standard voltmeter, using the shunt provided. A freshly charged automobile storage battery was used as a source of current, which was varied by means of a rheostat of large capacity. The leads to alternating current instrument were reversed as before, to correct for directional errors.

For calibrating the wattmeter, which was a Jewell instrument, serial number 760,260, the voltage was held at a practically constant value, using the "B" batteries, and the current, from the automobile storage battery, was varied as in the ammeter calibration. Again the leads to the alternating current instrument were reversed for each reading. The voltmeter just calibrated was used for checking the voltage, while the standard voltmeter, with its shunt was used to measure the current.

Tables of all these calibrations, together with the corresponding curves are given in the appendix.

Observations.

The motors were numbered consecutively as tested, their location being shown both by description, as well as, in the case of those motors which were in the large rooms with a great many other motors, on a chart showing their location. Thus, in case it was necessary to refer to any of these motors, it could be done easily.

Tables V to VIII give the data secured, with the meter readings corrected by means of the calibration curves shown in the appendix. Figures 7 and 8, also in the appendix, show the charts of motor locations, as mentioned above.

A total of four motors were not tested. Two of these were 6.8 horsepower motors on the elevators. They are run intermittently, and it was impossible to get a test under load, as they ran only from one floor to the floor above, a period too short to get a reading. One was a 30 horsepower motor which runs a baler. The load is a small fraction of this motor's capacity, and it runs at very infrequent intervals. It is more of a spare motor, which runs the baler when it is not needed to replace another motor which is in need of repairs. A fourth motor was a 7.5 horsepower motor used to run wood-working machinery and is lightly loaded and runs infrequently.

Calculations.

In the tables V - VIII (appendix), the calculations were relatively simple. From the two wattmeter readings at each load, the value of the power-factor, cosine theta, was obtained.Using this value, the potential and current values could be checked for accuracy, and as stated, new readings taken if the discrepancy was appreciable.

From the power-factors for the separate motors, the plant power-factor was calculated, that is for the motor load alone. The lighting load would of course raise this figure. The horizontal component of the resultant current would be the sum of the products of the individual currents, times the cosine of their angle of lag, while the vertical component would be the sum of the products of the individual currents times the sine of their angle of lag.Knowing these two components, the value of the resultant current would be the square root of the sum of their squares, and its angle of lag, or theta, would be the angle whose tangent was the vertical component divided by the horizontal component. The cosine of this angle would be the plant power-factor for the motor load. This would of course be on the assumption that the entire plant was operating at full load, which would probably be the case most of the time.

A rough estimate of the plant power-factor, including the lighting load could be made. Subtracting the maximum power taken by the motors from the average maximum demand for the day, would give the approximate lighting load in kilowatts. Assuming this to be at unity power-factor, it would be divided by 3 times the voltage to determine the resultant current. This, added to the horizontal current found for the motors, would give the horizontal component of the current for the entire plant, and with it and the vertical component used before, the resultant plant current and power-factor would be found as before. This power-factor would probably be even more inaccurate than that for the motors alone, but it does give an idea of the possible performance of the plant. These calculations follow.

Power-factor, Motor load only.

I_h Horizontal component of current	1778	Amp.
I_v Vertical vomponent of current	1053	"
I_t Total resultant current I_v^2 I_h^2	2066	"
Tangent theta I_v/I_h	.588	
Plant Power-factor(cosine theta)	.862	

Power-factor, assuming all lights on.

I_h' (I_h I_l) 50 kw. lights	1909	Amp.
I_v' (I_v)	1053	"
I_t'	2180	"
Tangent theta'	.552	
Plant power-factor (cosine theta)	.875	

In order to show how the amount of the power bill is determined from the contract shown in figure 1, the charts from the maximum demand indicator at this plant for the first three months of 1928, were borrowed from the Knoxville Power and Light Company. Photostatic copies of these charts are shown in figures 9 to 14 in the appendix. Also, the readings of the watt-hour meter for these three months were secured. With this data, the total charge for power during this period may be calculated. The charge as shown is the net bill only, as the gross bill is merely the net bill plus a penalty for failure to pay promptly.

Mo. 1928.	Kwh.	Energy charge.	Actual demand.	Billed demand.	Demand charge.	Total Net Bill
Jan.	90791	$771.72	691.2 Kw	691.2 Kw	$951.50	$1723.22
Feb.	134811	$1145.89	609.1 Kw	691.2 Kw	$951.50	$2097.39
Mar.	148167	$1259.42	652.3 Kw	691.2 Kw	$951.50	$2210.92

It will be noted that the maximum demand charge is the same for all three months. This is due to the fact that this charge may be fixed for twelve months, and it had been fixed at this figure some time in the last year. It was a coincidence that the maximum demand for January was the same figure. It will also be noted that there is no correction for powerfactor. As the plant powerfactor was shown to be above 80%, this would naturally be the case, as no credit is allowed for an amount greater than this figure. While the contract calls for an adjustment when this drops below 80%, this rule is not closely watched unless an excessively low figure is found to be the usual thing.

Conclusions.

From the maximum demand charts, it is evident that the distribution of demand is very smooth during the entire day. The variation is only such as would be unavoidable in the ordinary operation of the plant. It is evident that the motors are started over a reasonable period of time, and that there is not a great deal of starting and stopping during the day. Another factor which helps to keep down the maximum demand is the care taken to see that the belts are all on the idler pulleys before starting up a motor. While this is primarily for the purpose of eliminating belt breakage or slipping off, it also serves the purpose of keeping down the starting current very well.

Most of the motors operate at a good power-factor, considering that they are induction motors. They have enough leeway in this respect to take care of reasonable load changes without becoming excessively low. The plant power-factors, 86% for the motors alone and 87.5% for the motors and assumed lighting load, are very good for such a plant. While these figures are not accurate, due to the assumptions that had to be made to arrive at the results, they are not a great amount off. With the exception of a few motors which are operating at a very low load, with consequently low power-factor, and one motor which is greatly overloaded, all of the motors are operating at about as good economy as could be desired.

It will be noted that tho the maximum demand for the month of January is greater than for the two succeeding months, the energy used is less. Evidently the plant was running at a full load during the day, and but little at night. Examination of the demand charts show that there was considerable night running during February and March, tho not in a quantity sufficient to affect the maximum demand for the day. In fact the plant seems to have run at a somewhat smaller load during these months. This might lead to the idea that by running the plant half during the day and half during the night, the power bill might be reduced. However, the saving in maximum demand charge would probably be more than offset by the extra power used for lighting.

On the whole, it seems that the plant operates at about as economical a program as possible. The motors are, on the whole, loaded sufficiently to operate at a good efficiency. This keeps down the energy charge. The operation is so arranged that the maximum demand is not a high peak compared to the average demand. This keeps down the maximum demand charge. Finally, a good power-factor is maintained, so there could be no possible reason for any penalty from this source.

Table I

Calibration of Weston Laboratory Standard Voltmeter, against Potentiometer and Standard Cells.

Standard Voltmeter reading,	Potentiometer reading corrected to standard cells.
.1000 v	.0995 v
.2000 v	.1999 v
.3000 v	.3001 v
.4000 v	.4002 v
.5000 v	.5002 v
.6000 v	.6002 v
.7000 v	.7002 v
.8000 v	.8003 v
.9000 v	.9003 v
1.0000 v	1.0004 v
1.1000 v	1.1004 v
1.2000 v	1.2005 v

Table II

Calibration of General Electric A.C.Voltmeter

No. 510,644, against Weston Standard Voltmeter.

G.E.Voltmeter reading.	Standard Voltmeter reading (corrected)
20.0 v	19.99 v
30.0 v	30.01 v
40.0 v	40.02 v
50.0 v	50.02 v
60.05 v	60.02 v
70.08 v	70.02 v
80.10 v	80.03 v
90.05 v	90.03 v
100.05 v	100.04 v
110.05 v	110.04 v
120.05 v	120.05 v

Table III

Calibration of Weston Alternating Current Ammeter

No.39,762 against Weston Standard Voltmeter and Shunt.

Weston A.C. Ammeter reading.	Mean.	Standard Voltmeter reading (corrected)
1.050 1.000	1.025 Amp.	.995 Amp.
1.480 1.525	1.502 Amp.	1.499 Amp.
2.010 1.960	1.985 Amp.	1.999 Amp.
2.460 2.510	2.485 Amp.	2.5002 Amp.
3.020 2.970	2.995 Amp.	3.001 Amp.
3.460 3.510	3.485 Amp.	3.501 Amp.
4.010 3.975	3.992 Amp.	4.002 Amp.
4.470 4.520	4.495 Amp.	4.5002 Amp.
5.005 4.975	5.000 Amp.	5.002 Amp.

Table IV

Calibration of Jewell Wattmeter No.760,260, against Weston Standard Voltmeter with Shunt and G.E.Voltmeter calibrated in Table II

Jewell Wattmeter reading.		Standard Voltmeter reading (corrected).		G.E.Voltmeter reading (corrected)
50.0 51.0	51.5 Watts.	.495 Amps.	49.0 Watts	99 Volts
101.0 103.0	102.0 "	.990 "	98.0 "	99 "
154.0 152.5	153.3 "	1.495 "	148.0 "	99 "
202.0 199.0	200.0 "	1.995 "	197.5 "	99 "
252.0 250.0	251.0 "	2.510 "	248.2 "	98.9 "
302.5 299.8	301.2 "	3.020 "	298.5 "	98.9 "
345.0 349.0	347.0 "	3.530 "	349.0 "	98.9 "
393.0 396.0	394.5 "	4.040 "	399.0 "	98.9 "
450.0 450.0	450.0 "	4.520 "	448.0 "	98.8 "
498.0 502.0	500.0 "	5.005 "	497.0	98.8 "

Table V

Motor No.	Location	Current Fr. Load	Current Full Load	Voltage Fr. Load	Voltage Full Load	Powerfactor Fr. Load	Powerfactor Full Load	Rated Hp.	Input Hp. Full. load	Input Watts Full load Kw	Remarks
1	Spinning Room	70.2	127	225	224	.364	.894	75	58.9	44.	
2	Spinning Room	106	110.5	224	224	.785	.895	75	50.1	38.4	
3	Carding Room	44.4	92.8	231.5	233	.480	.891	50	43.9	32.7	
4	Spinning Room	59.2	150	225	222.5	.383	.858	75	69.7	52.0	
5	Picker Room	64.8	125.2	220	221	.220	.970	30	60.4	45.0	This motor was carrying almost twice its rated load, so another motor was put in to take part of the load, so 5 was tested again.
5a	Picker Room		117.		214		.931	30	54.0	40.4	
6	Carding Room	29.7	48.8	223.5	223.	.460	.963	25	24.2	18.15	
7	Carding Room	20.8	33.3	226	226	.343	.760	15	13.25	9.9	

Table VI

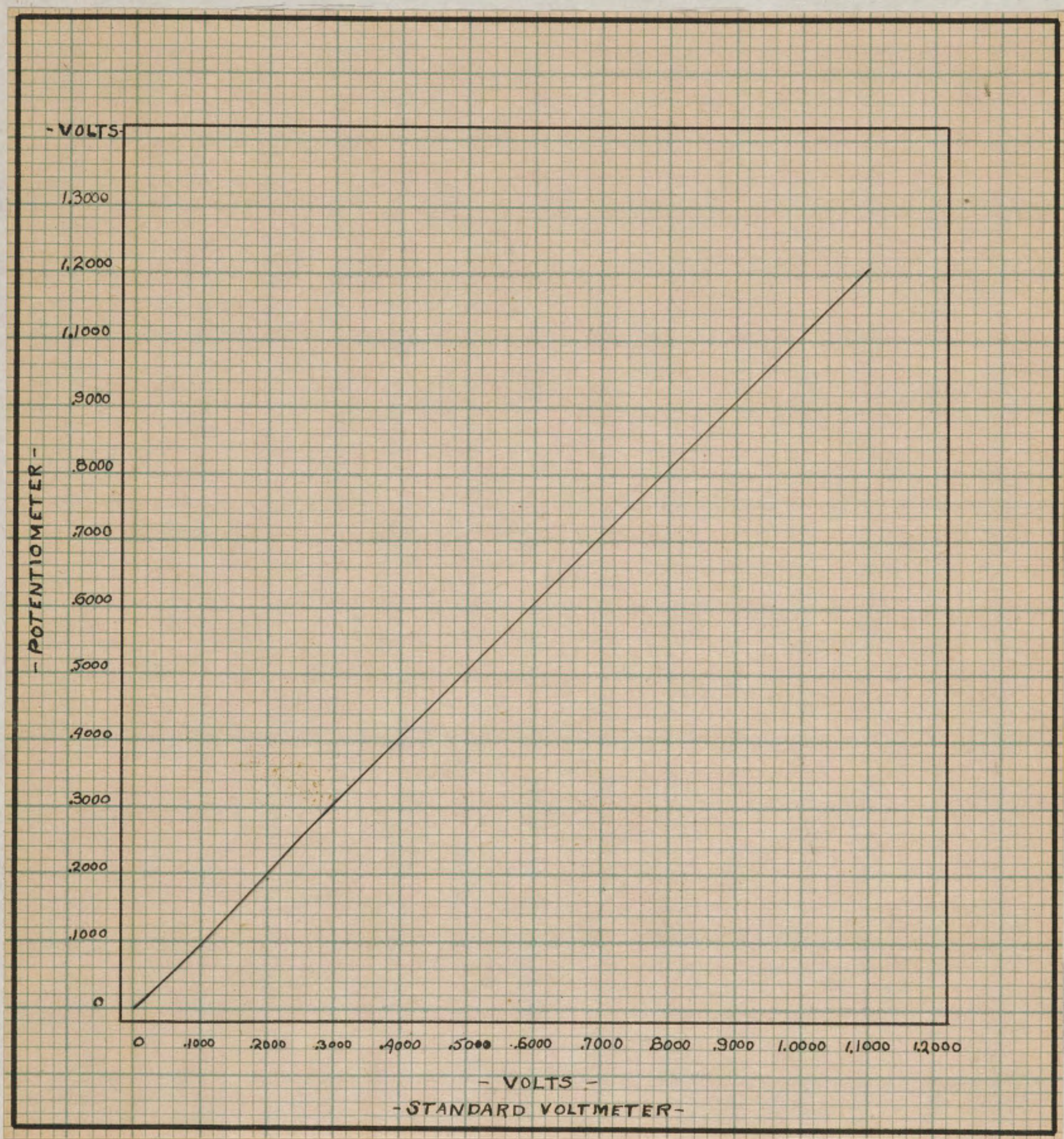
Motor No.	Loaction	Current Fr. Load	Current Full Load	Voltage Fr. Load	Voltage Full Load	Powerfactor Fr Load	Powerfactor Full Load	Rated Hp.	Input Hp. Full Load	Input Kw Full Load.	Remarks
8	Picker Room	36.6	57.4	228	228	.382	.785	40	23.6	17.6	
9	Twister Room	43.1	79.0	213	209.5	.390	.843	40	32.4	41.0	
10	Twister Room	39.6	67.0	213	211	.300	.835	40	27.4	20.4	
11	Twister Room	26.5	30.7	212	212	.164	.655	25	9.92	7.4	Somewhat under-loaded, giving low power factor.
12	Opener Room	11.7	13.4	218	216.8	.520	.813	10	5.47	4.08	Friction load includes part of the regular load.
13	Drying Room		25.9		223.5		.717	15	9.13	7.19	Load cannot be taken off.
14	Picker Room	21.3	24.0	219	219	.753	.787	15	9.57	7.12	This motor is named "Old Hulda"
15	Spinning Room	66.9	81.0	218.5	218.3	.300	.700	75	28.7	21.4	

Table VII

Motor No.	Location	Current Fr. Load	Current Full Load	Voltage Fr. Load	Voltage Full Load	Powerfactor Fr. Load	Powerfactor Full Load	Rated Hp.	Input Hp. Full Load	Input Kw. Full Load	Remarks
16	Spinning Room	69.5	105.	218.5	217.5	.305	.808	75	41.8	31.2	
17	Spinning Room	65.8	106.5	220.5	219.5	.350	.823	75	44.5	33.2	
18	Spinning Room	72.0	105.5	224	224	.346	.837	75	44.6	33.4	
19	Spinning Room	21.0	44.2	220	219.5	.341	.881	25	19.7	14.7	
20	Spinning Room	21.3	41.5	220.	219.	.344	.892	20	18.8	14.0	
21	Spinning Room	39.2	88.0	215.	214	.371	.881	50	38.4	28.7	
22	Spinning Room	52.5	124.5	219.	216.5	.275	.888	60	55.6	14.55	Load varies thru a wide range, due to type of machine.
23	Speeder Room	40.8	81.3	225.	223.5	.285	.864	40	35.9	27.15	

Table VIII

Motor No.	Location	Current Fr. Load	Current Full Load	Voltage Fr. Load	Voltage Full Load	Powerfactor Fr. Load	Powerfactor Full Load	Rated Hp.	Full Load Input Hp.	Full Load Input Kw.	
24	Speeder Room	34.6	70.0	224.	224.	.32	.91	40	33	24.6	
25	Speeder Room	30.	43.6	218	216	.45	.849	25	18.5	13.8	
26	Speeder Room	25.	32.	216	216	.398	.732	20	11.65	8.7	
27	Basement Under Spin.Rm.	34.7	88.4	214	210	.428	.884	30	22.8	17.0	
28	Basement under Spinn. Rm.	20.8	43.6	214	211	.379	.963	20	20.6	15.36	
29	Dye Room Cent. Dryer	15.5	32.8	216	214	.27	.943	15	14.9	11.1	
30	Dye Room Picker		15.8		214		.910	7	7.1	5.28	
31	Dye Room Sampler	2.43	3.1	217	217	.438	.528	3	.83	.61	
32	Machine Shop		7.1		220		.75	7.5	3.64	.21	



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1.2000
1.1000
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.8000
.7000
.6000
.5000
.4000
.3000
.2000
.1000
0
- POTENTIOMETER -
0
.1000
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.4000
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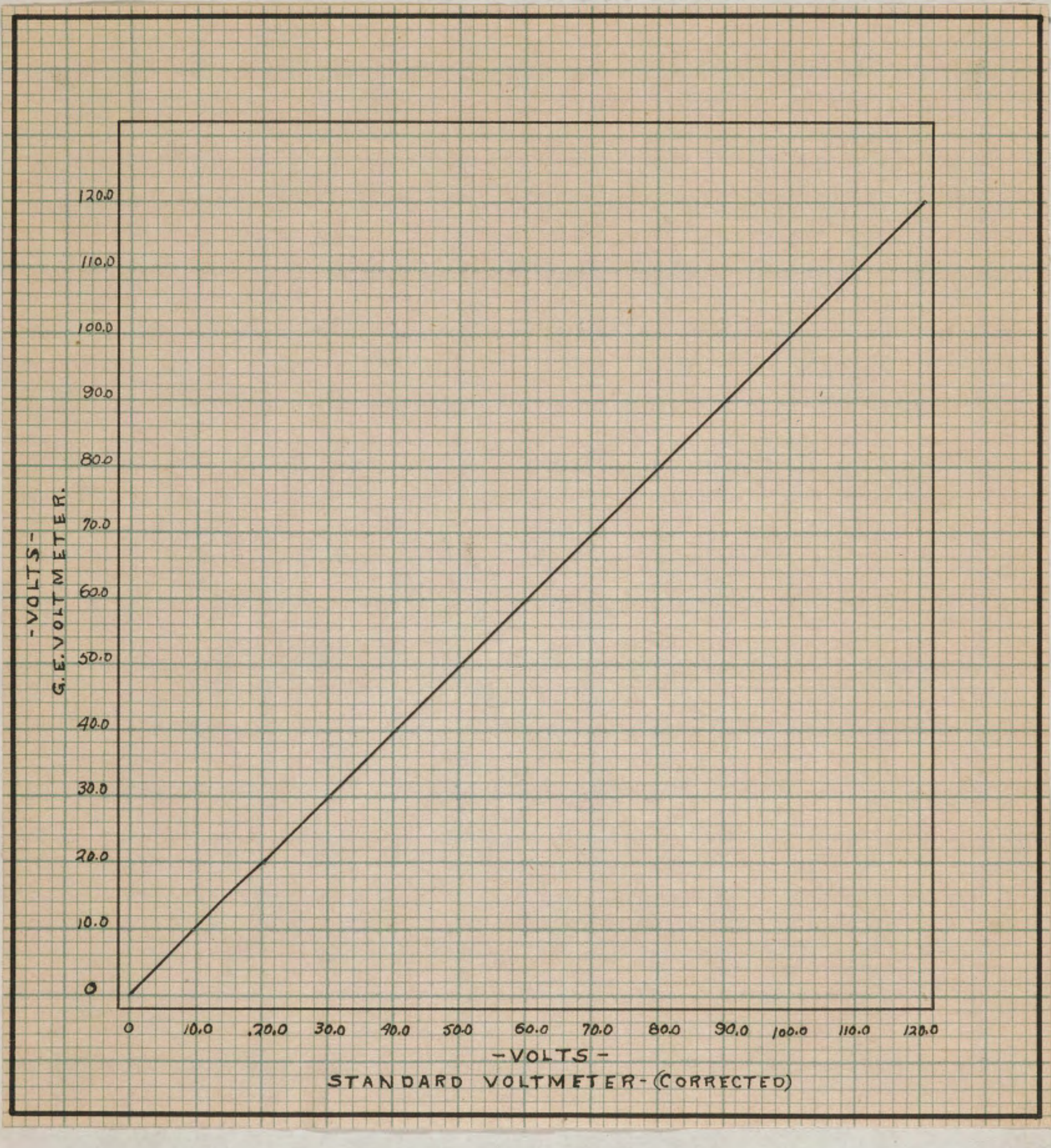
.9000
1.0000
1.1000
1.2000
- VOLTS -
- STANDARD VOLTMETER -

Figure 3



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G.E. VOLTMETER.
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10.0
20.0
30.0
40.0
50.0
60.0
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90.0
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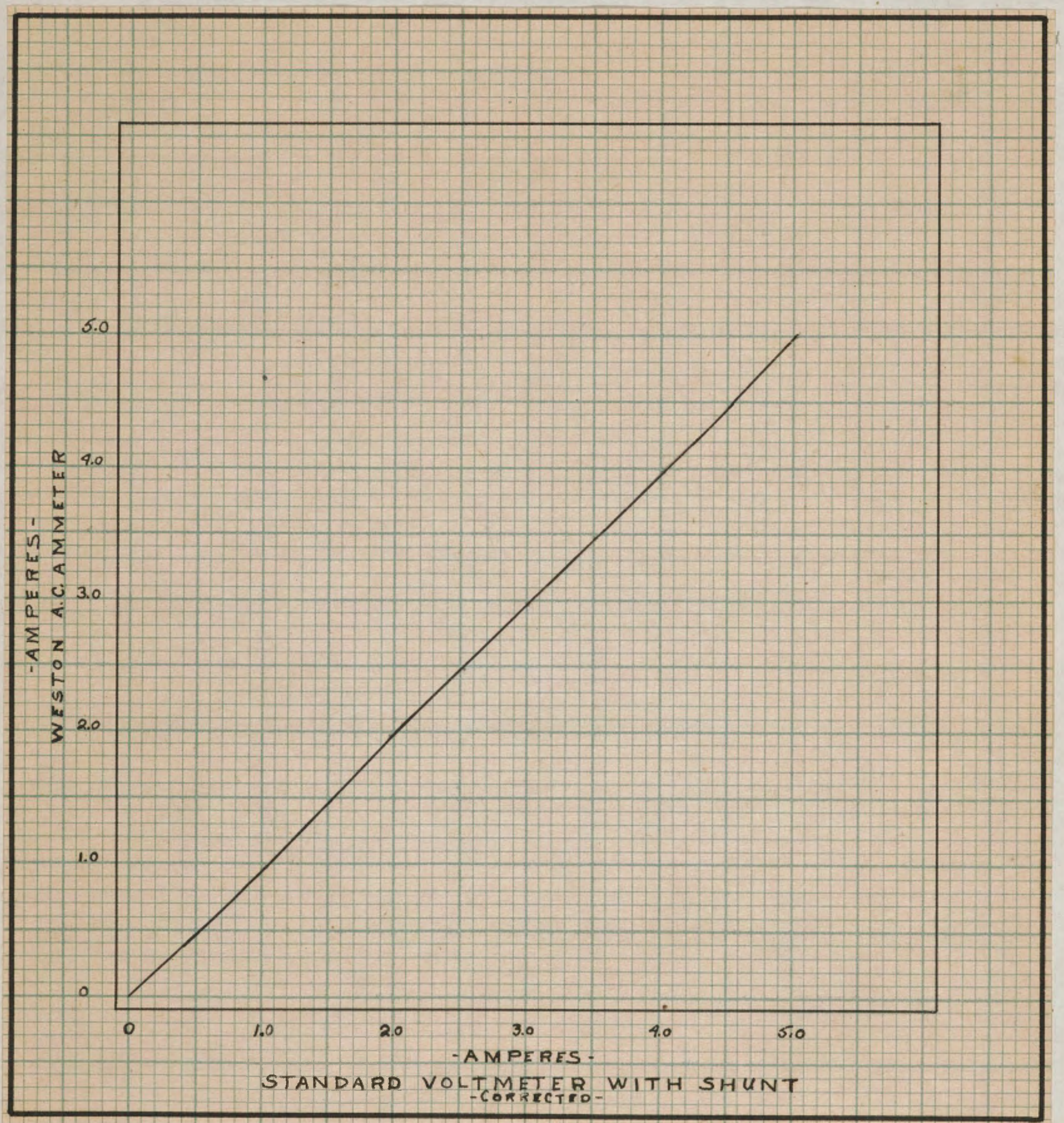
STANDARD VOLTMETER-(CORRECTED)

Figure 4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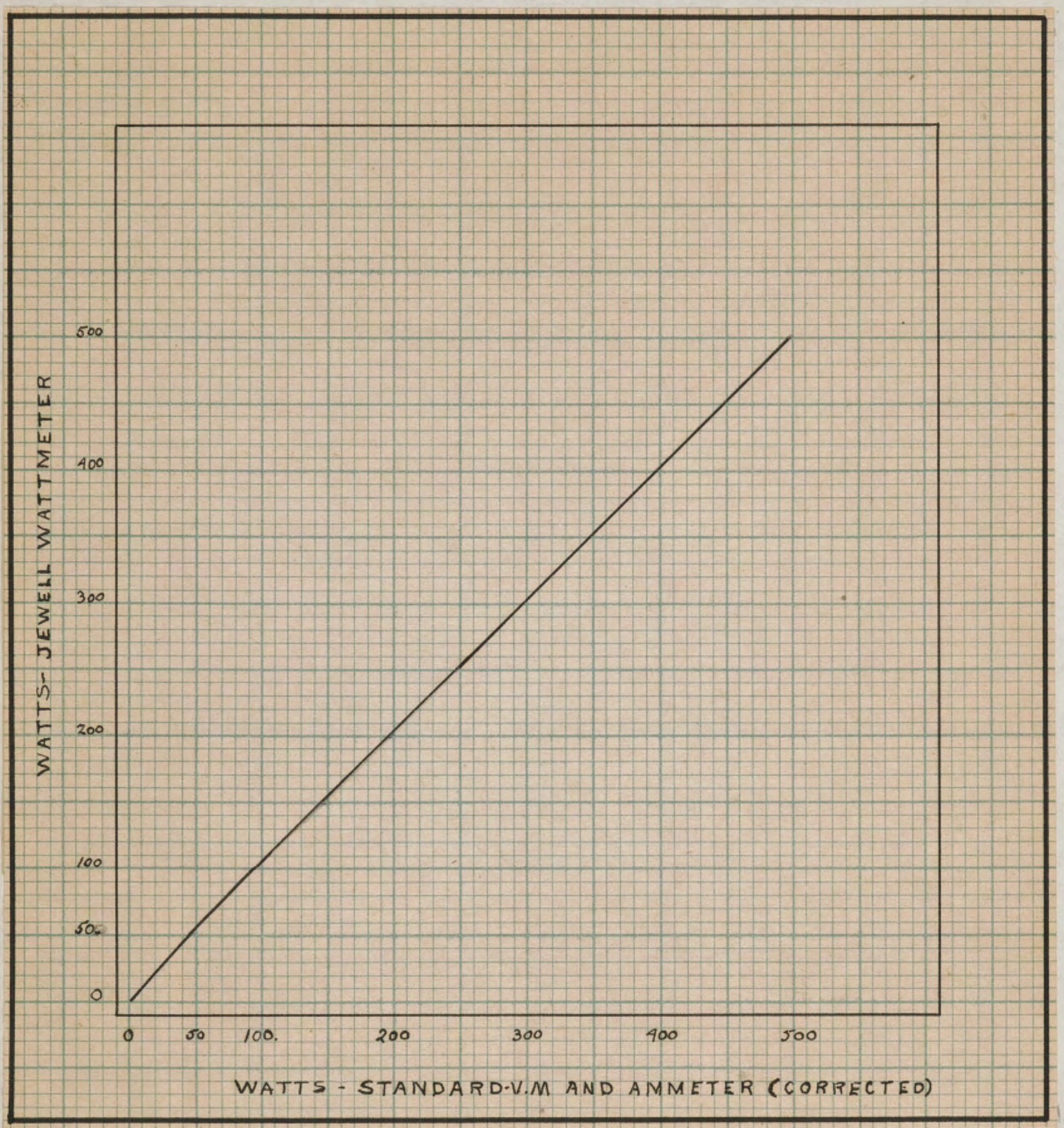
STANDARD VOLTMETER WITH SHUNT
-CORRECTED-

Figure 5


WATTS- JEWELL WATTMETER
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300
200
100
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100.
200
300
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WATTS - STANDARD-V.M AND AMMETER (CORRECTED)

Figure 6

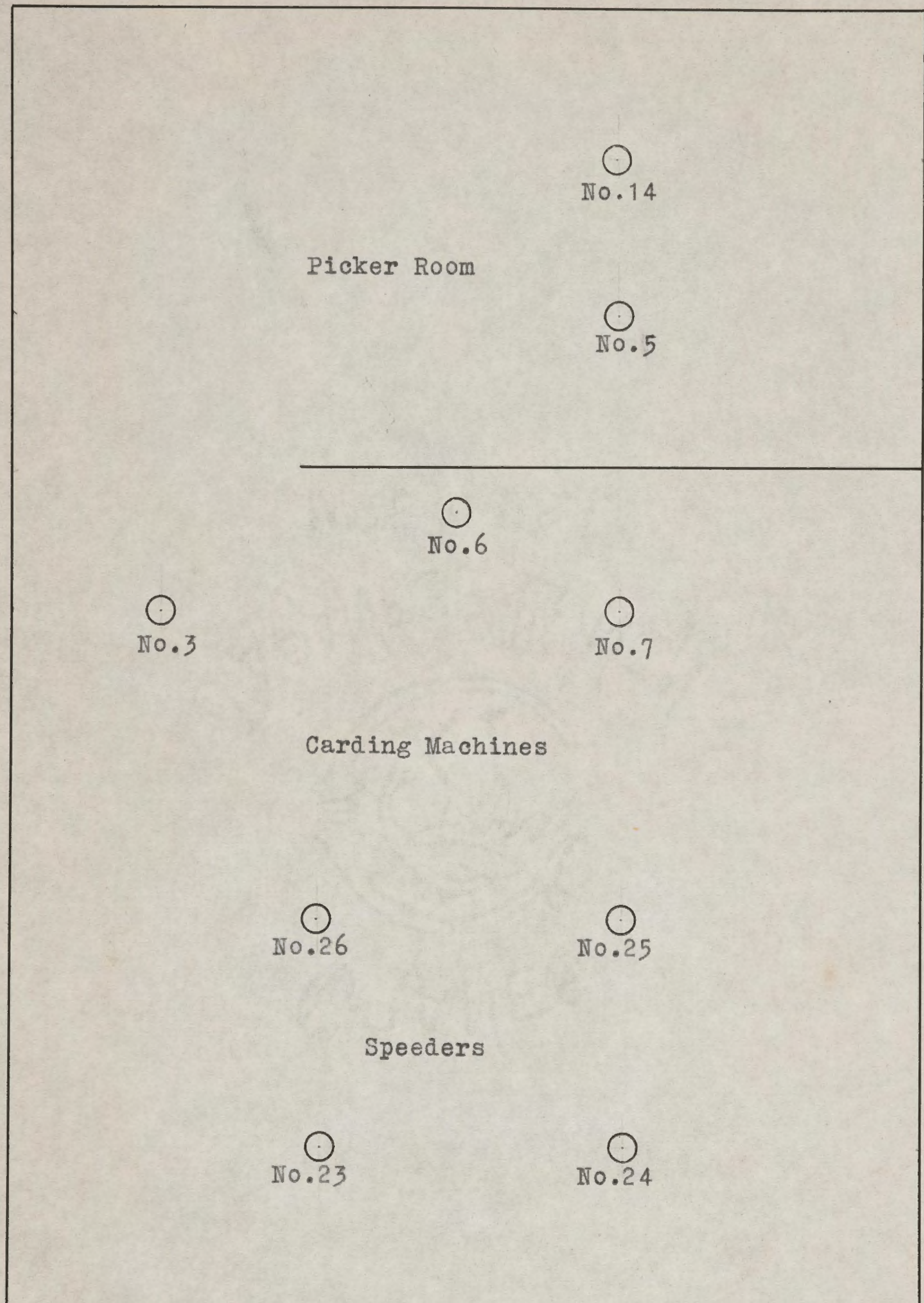
No.14
Picker Room
No.5
No.6
No.3
No.7
Carding Machines
No.26
No.25
Speeders
No.23
No.24

Figure 7

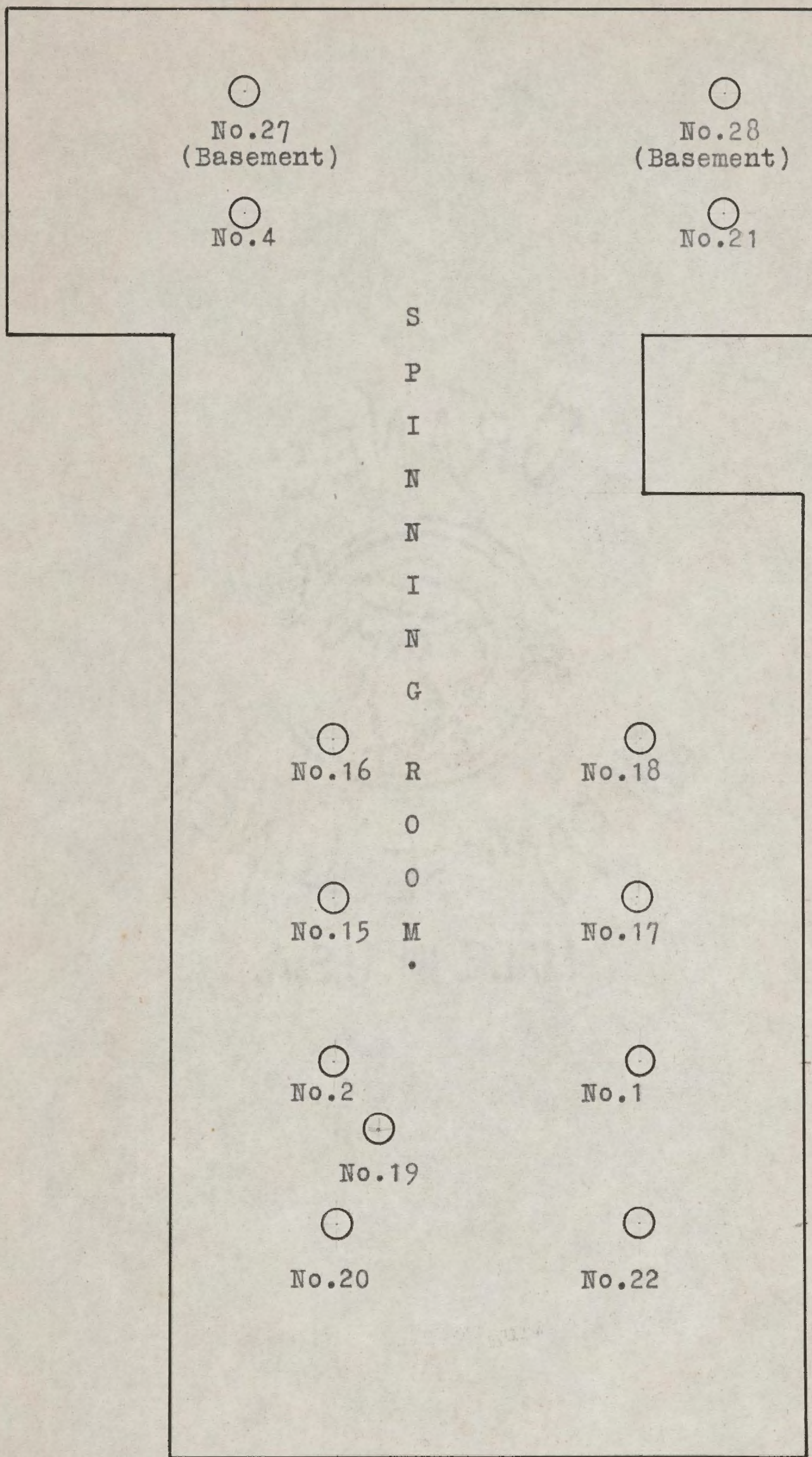
No.27
(Basement)
No.28
(Basement)
No.4
No.21
SPINNING ROOM.
No.16
No.18
No.15
No.17
No.2
No.1
No.19
No.20
No.22

Figure 8

Figure 9.

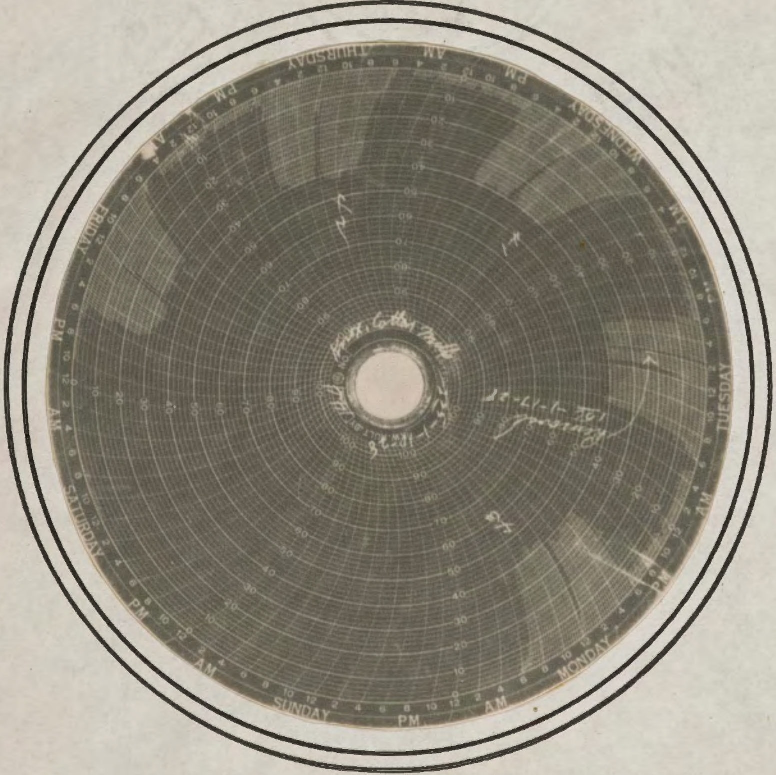

Figure 10.

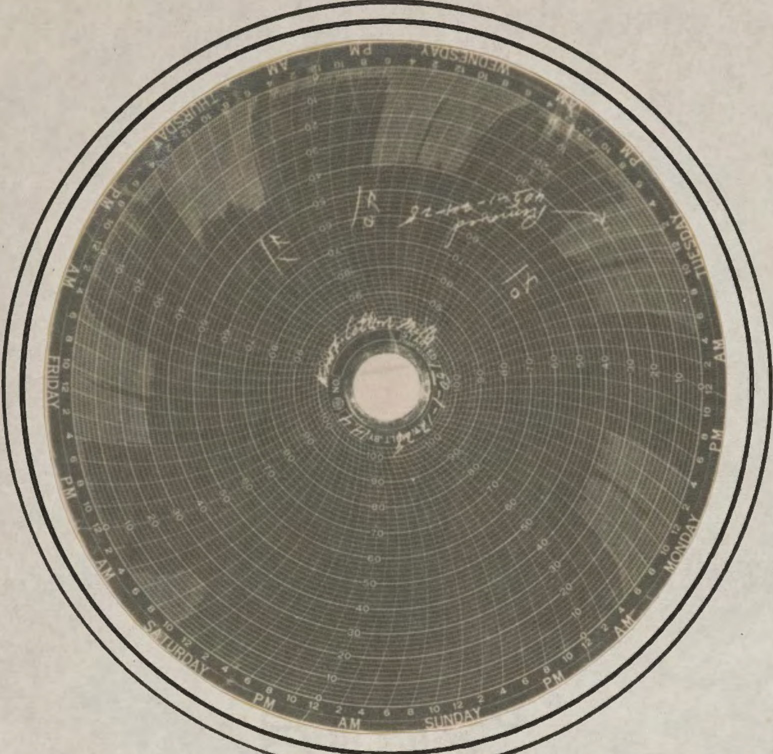

Figure 11

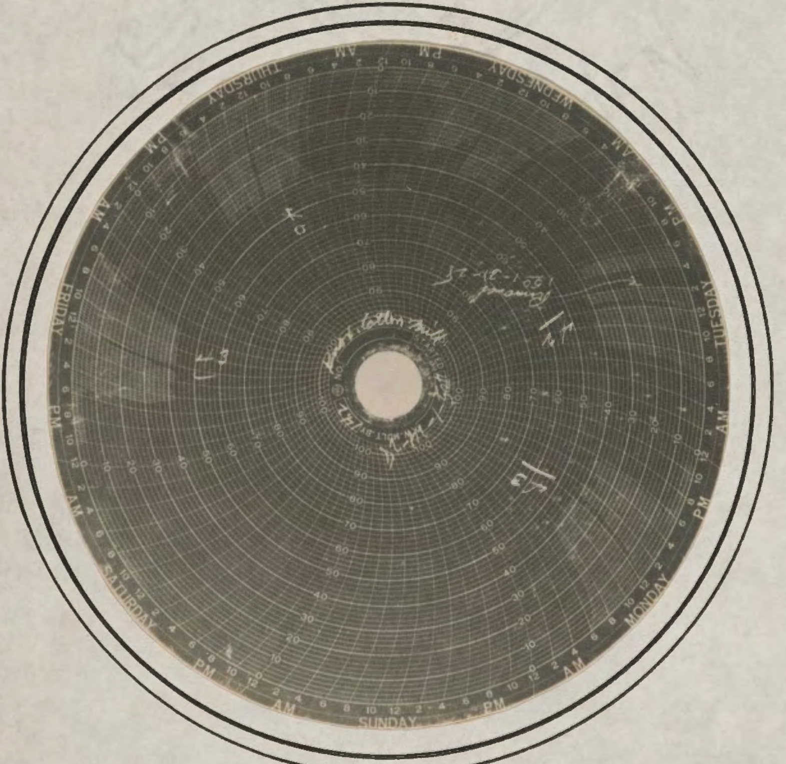

Figure 12

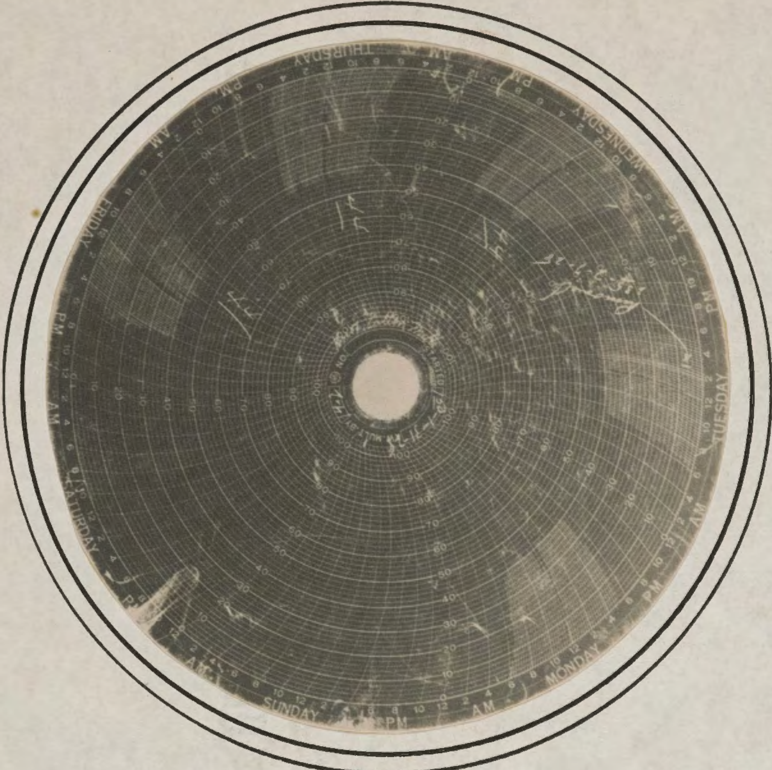

Figure 13

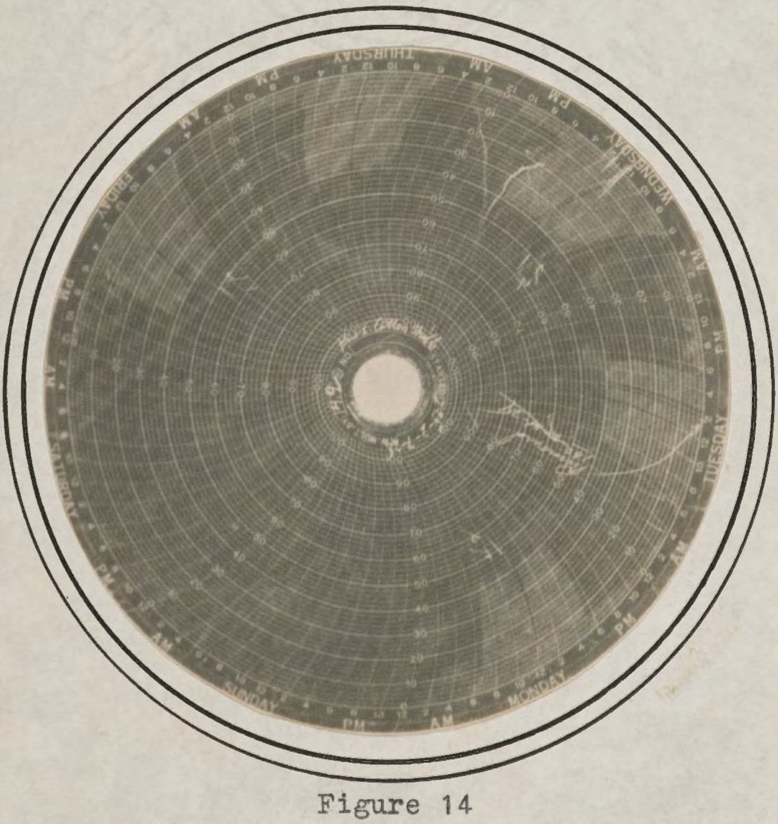

Figure 14

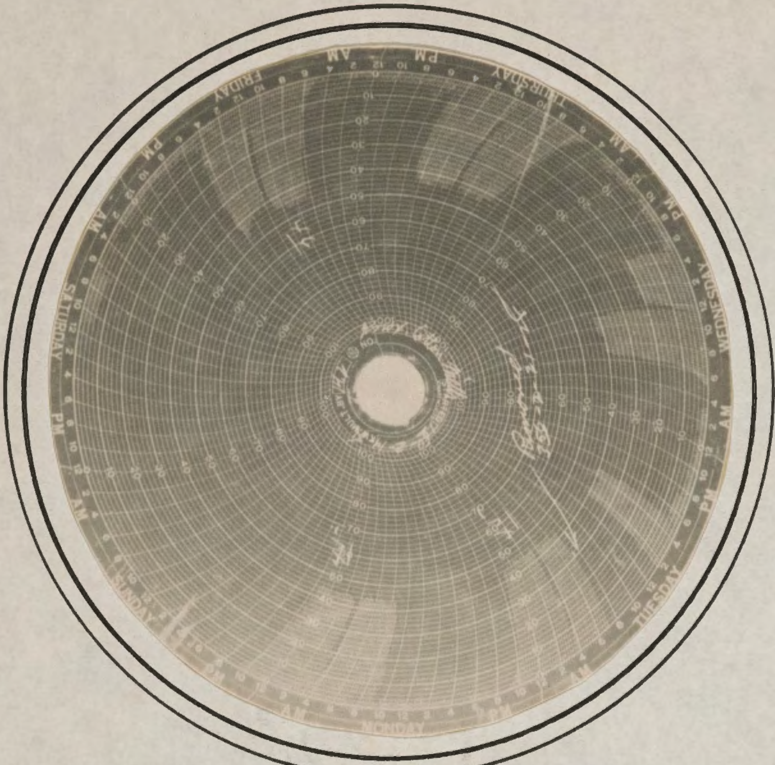

Figure 15

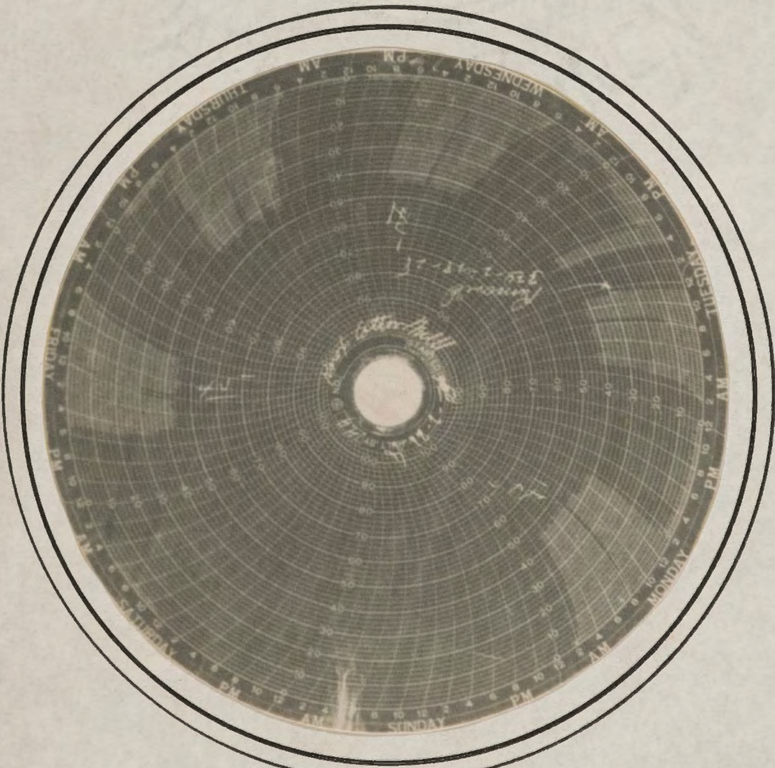

Figure 16

Figure 17

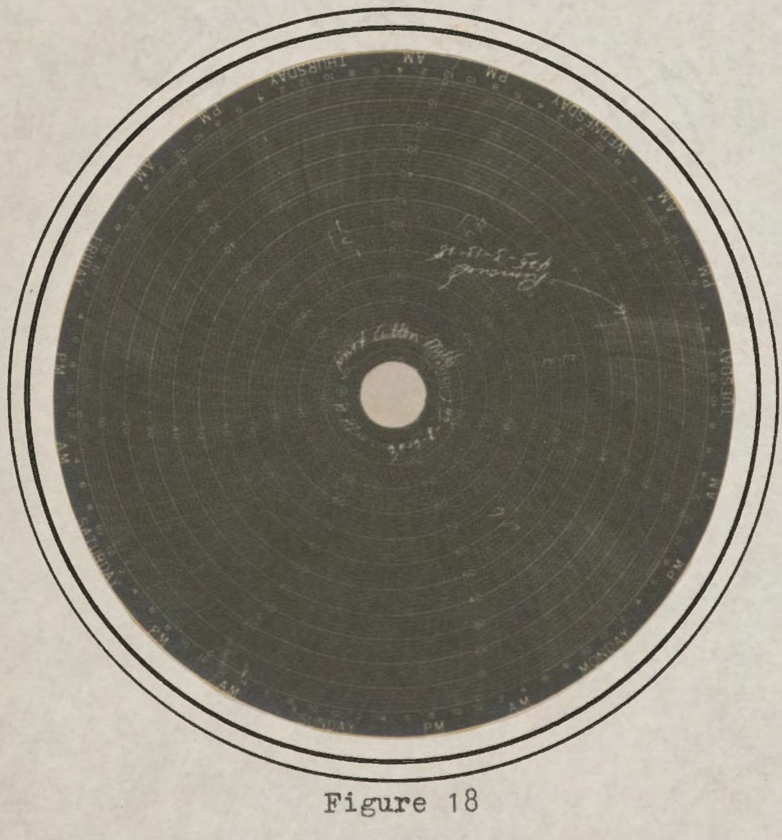

Figure 18

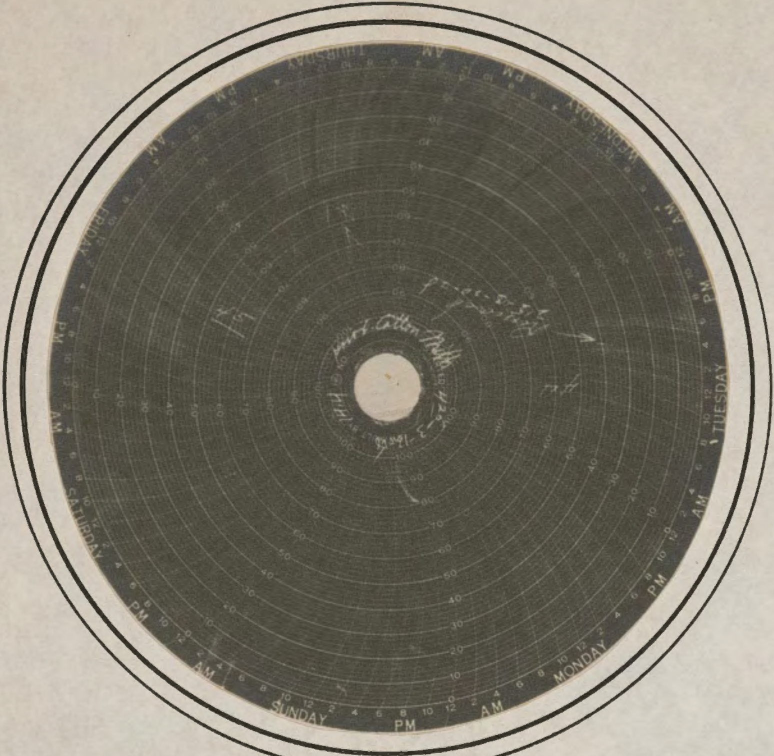

Figure 19

Figure 20

APPROVAL

The foregoing thesis is hereby approved as a creditable study of an engineering subject, carried out and presented in a manner sufficiently satisfactory to warrant its acceptance as a prerequisite to the degree for which it is submitted. It is to be understood that by this approval the undersigned does not necessarily endorse or approve any statement made, opinions expressed, or conclusions drawn therein, but approves the thesis only for the purpose for which it is submitted.

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