IMPROVEMENTS IN INSTALLATION AND OPERATION

OF

THE ELECTRICAL SYSTEM

OF

A LARGE MANUFACTURING PLANT

A thesis submitted to the faculties of
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By

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PREFACE

It is well known by those who have been intimately connected with Industrial Plants that an electrical power installation, which though well designed at first, becomes constantly changed as the Plant is operated until at the end of a period of years, motors are found operating at other than rated loads, lines over-loaded and over-fused and an ever increasing corps of electrical maintenance men repairing rather than preventing breakdowns.

Usually the proper installation was not specified in the beginning, due to several separate agencies being employed such as: the Electrical Wiring Contractor; the Manufacturers of Driven Machines who specify their driving equipment; and the Central Station or Electrical Company which installs the electrical substation. No capable engineer is employed to supervise the complete electrical installation to provide an efficient system and for future developments.

In 1921 an investigation was started of the electrical power installation of a large manufacturing plant in Kansas City, Missouri. This Plant had been in operation twelve years and at the time was typical of the foregoing conditions. The results of this investigation are given in the following thesis, together with improvements made and recommended.

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INTRODUCTORY

In Kansas City, Missouri, a typical city of the middle west, is a standard type of manufacturing plant producing a finished product from the rough,composed of a foundry, machine shop and shipping department.

In 1921 and since, it has been possible to make a series of electrical tests in this factory and to investigate the electrical installation.

The plant under consideration occupies a main building having general dimensions of 1000 feet in length and 250 feet in width, the employees number 1200 men, and it has a connected horse-power of approximately 1500 in electric motors. This plant produces steel castings from 10 pounds to 1500 pounds in weight. These castings in turn are machined and assembled into a finished product.

The factory is divided into two divisions because of the difference in product, namely, Large Casting and Small Casting divisions. Each has its own core making department, cupola, foundry, machine shop, assembling and shipping department.

At the present time electrical power is purchased from the Kansas City Power & Light Company at 13,200 volts and is transformed to 440 volts by means of a 1000-kv-a. transformer substation consisting of three 333-kv-a. transformers. This power is then transmitted to a main switchboard at approximately the center of the machine shop and from there it is distributed throughout the factory.

Transportation of castings within the factory is by means of elevating trucks, both electric and gasoline. All hoisting is done by means of compressed air hoists operating over a limited area on a track. The electrical system within the factory is composed of motors to furnish all mechanical power. The air compressor units require the largest horse-power in the aggregate.

In 1921 when the first test was made upon this factory it had been in operation twelve years and the electrical system (considered adequate at the time of installation) had been so changed, added to and poorly maintained, that the motors were operating under-loaded and over-loaded. The transformer substation was greatly over-loaded. The additions since the original installation had been installed by unskilled labor and, therefore the electrical system of the plant as a whole was in the condition of the average factory in this locality, after several years of operation. This report will show certain results obtained from an electrical investigation.

ELECTRIC MOTORS

In 1921 the connected horse-power in electric motors was 1540. The average load on the plant was 240-Kw. giving a connected load factor of 18 per cent and therefore tests were made upon the individual motors to determine the loading. This was done by means of an Esterline graphic wattmeter and ammeter and an indicating voltmeter. It was found, after several tests with a graphic voltmeter, that this instrument was not necessary. The time of day as well as meter readings was essential in that it was later made use of in considering the load and the maximum demand.

Motors were divided into two classes, those operating under a steady load and those operating under a fluctuating load. The motors operating under a steady load were investigated with very little trouble; but in each case the load was checked to see that there was no condition over the operating period that changed it from the apparent steady value. On the other hand the motors with the fluctuating loads constituted the greatest problem and in this case the graphic ammeter was the important instrument in that the heating of motors is proportional to the square of the current. Several specific cases will be described under the heading of the driven machine.

Surfacing Machines

Surfacing machines are used in the Large Casting division for grinding casting surfaces and each consists of two 6-foot grinding wheels so spaced that two sides of a casting may be surfaced at the same time. Where there were two complete machines each driven by a 50 horse-power motor, it was found by test that each of these machines operated over a period at 100 per cent load but that the peak loads of the two machines did not coincide. It was, therefore, recommended at once that both surfacing machines be connected to one of the 50 horse-power motors. This was done using a clutch so that the motor could be started without having to accelerate under the load due to the inertia of the grinders, and this system of operation has been satisfactory since. It might here be noted that the factory that builds these machines was notified and five sets that were coming through on production were built with the elemination of one 50 horse-power motor from each combination.

Graph number 1 shows a wattmeter graph before the change and Graph number 2 and 2-a the wattmeter and ammeter graphs when two machines were driven by one motor. It will here be noted that the charts before and after are slightly at variance as to values, due to the different types of castings being surfaced during the tests, but the general principle still holds. It is of interest to note that the peak load was not changed. This was checked by noting the operation of the machines in which it is always the case that the peak on one machine can not occur at the peak time on the other.

Reaming and Tapping Machines

During the finishing of the castings it is necessary to ream and tap certain parts. In some cases it is necessary to ream and tap seven openings as large as 3½ inches in diameter. This is accomplished by means of specially built machines driven by direct-connected motors. The feed for these machines is of a manual control type operating through an hydraulic attachment and it was found that, as a general rule, the peak loads on these machines reached values up to 300 per cent load. A careful investigation of the load curves as shown typically in Graph number 3 revealed only full load operation on a current basis, but maintenance on these machines during the years of their installation had left the circuits fused to the point of practically no protection. It was, therefore, necessary on these machines to locate a protective device that would suffice to adapt the system, with the least amount of change, to comply with the National Electrical Code of Fire Underwriters. Therefore, thermal relays were installed in which the heating curves of the relays corresponded in a general way to the heating curve of the motors. These relays were adjusted and maintenance men given strict orders not to tamper with them. The result in actual operation is that if the operator of the machine works the machine too hard, the relay will trip. This causes him trouble in the operation of his machine and also makes it necessary for him to wait until the relay cools to a point sufficient to allow starting again. Since this work is of the piece work type in which the operator is paid on the basis of number of castings the operating difficulty is solved.

Another interesting machine is a 75 horse-power motor operating a line shaft on which there are several small reaming and tapping machines. Graph number 4 shows the graph of this motor. It has, on a heating basis, been carrying 13 per cent over-load for several years. The 13 per cent over-load being based upon a continuous rating of 90 horse-power. This situation has been repeatedly reported to the management who has so far failed to make a change. Experiments, however, have been made on equipping the driven machines with small direct-connected motors and it is evident, from an operating standpoint, that this is desirable because the failure of the one large motor would shut down the whole system and also because these individual machines do not operate continuously together. An appropriation has been requested to make each driven machine individually motor driven.

Sand Mixing Machines

A standard type squirrel cage induction motor was installed on one of the sand mixing machines in the foundry. This motor, as well as the others in the foundry, had caused a great deal of trouble and had been re-wound several times. Also, at times, it had been increased in size, on replacement, until 10 horse-power was reached. It was found upon investigation that the dust in the foundry had been the cause of the trouble both in getting into the oil, and thereby causing the bearings to wear rapidly, and also gathering on the coils of the motor and so decreasing the radiation that the motors increased in heating and failed under an 80 per cent load even when the bearings were not ruined. It was then recommended that a completely enclosed motor be installed for this work. A 15 horse-power enclosed motor was installed the increase in capacity being due to an estimated future load increase, but to date this load has not developed. The enclosed motor has now been operating for two years and when opened each six months it is found that no dust has seeped in or into the bearings. Therefore, the totally enclosed motor will pay for itself when operated in a dusty place, and doubly so, if the dust is of such a nature that it will effect the bearings.

Variation in motor speed is not required any place in the factory with the exception of fans in the ventilating system.

This covers the principal points in the operation of the motors in this plant, but this survey showed that squirrel cage type induction motors and slip-ring type were used with apparently no degree of reason. Squirrel cage motors were used where high starting torque was required and slip-ring type where low starting torque was required. The conditions so far depicted are no worse in this plant than in any other plants of the same character as none of these factories employ an electrical engineer. The work is carried on by an electrician under the supervision of a general engineer.

POWER WIRING AND CONTROL APPARATUS

As stated previously, when this test was started, lines were found to be over-loaded, over-fused and the wrong type of protective apparatus installed, which again is of common occurrence in the plants in this section of the country, therefore, a detailed inspection was made of the power wiring. An electrical construction company was hired to rectify the more flagrant violations of the National Electrical Code. One idea ever in mind was to eliminate as many fuses as possible. For instance branch circuit fuses were eliminated by running the same size wire to all motors on the same branch and a survey has shown that the fuses on lines rebuilt have rarely blown since their installation. The point has constantly been brought to the attention of the management that fuses, when properly installed, do not blow except in case of trouble.

It was found that renewable fuses were used throughout the factory and, according to common practice of the incompetent maintenance men and engineer, when a fuse blew it was refilled with twice as many fuse links and in some cases as many as seven were found. In other cases copper wire was discovered within the fuse casing. The reason for this over fusing in every case was first some failure of the motor, legitimate or otherwise, or poor contact of the fuse which caused it to heat, then the gradual increasing of the number of links as blowings repeated. Incidentally, increasing of fuse links in enclosed fuses does not increase the current carrying capacity of the fuses in the proportion usually considered by the electrician and certainly not when the fuse blew due to poor contact, either in the fuse block, clip or within the fuse at the points where the links are attached.

One interesting point was found on the lighting circuit, where fuses of the 600 volt, 600 ampere type were installed and within these fuses were seven 200 ampere fuse links. A test made on the system showed the maximum load to be 480 amperes. The fuses blew constantly, and no matter how clean their contacts were made, these fuses would blow. They were, however, replaced by two enclosed 600 ampere, 600 volt fuses after the fuse block contacts had been carefully cleaned and tightened. These did not blow until the contacts again caused trouble. However, the management considered the recommendation to install a circuit breaker on the lighting circuit and this circuit breaker set at 500 amperes has never tripped.

In this work several types of manufacturers equipment for operating of small motors were tried out and the time limit cut-outs were found to be the more adaptable on motors of 5 horse-power and less.

It has been recommended to the management that it change its policy in regard to the electrical equipment and employ an electrician who understands the National Electrical Code and who understands maintenance from the viewpoint that a motor properly loaded and maintained will rarely cause trouble. The average maintenance man will let what he calls "good enough" alone and therefore act only in case of trouble.

TRANSPORTATION SYSTEM

In the transportation system there are several electrical lifting trucks. These electric trucks are "Mercury" and "Elwell Parker," some are equipped with Edison batteries and some with lead plate cells. It was found on investigating the charging equipment that two generators were used operating at 120 volts and the voltage decreased in charging equipment resistence to approximately 60 volts for charging the batteries. A local repair shop re-connected one of the machines to operate at 60 volts and it has been satisfactorily carrying the entire load for over two years. This was an actual saving in kilowatt hours of 50 per cent of this particular load.

TRANSFORMER SUBSTATION

The transformer substation in 1926 consisted of three

200-kv-a. 60 cycle, 13,800/460 volt transformers. A test made at this time showed, as mentioned before, a maximum demand of 584 Kw. at 72 per cent power-factor or 811-kv-a. making an over-load of 32 per cent on the transformers.

Thermometers were placed on the outside of the tanks 2 feet from the top and bottom. The bulbs were covered with putty. A temperature rise was shown to be 38 degrees centigrade above the room temperature. It was, therefore, reported to the management, that with this temperature rise on the outside of the case, a greater rise would take place in the winding and assuming a temperature drop of 20 degrees through the oil, and 5 degrees through the case, an internal rise in temperature of 63 degrees centigrade would be indicated. While this test was not conclusive, it sufficed to warn that a failure was to be expected in the warm summer months. This failure actually occurred and the transformer substation was replaced with three 333-kv-a. transformers and, whereas the above station had been of the indoor type, the new transformers were installed on the outside. This station operated for a time at about 80 per cent load, but within a year it was practically fully loaded and in December, 1925 the load had increased to 921 Kw. maximum demand or 1280-kv-a. at 72 per cent power-factor. This gave an over-load on the power bank of 28 per cent and, therefore, the management was warned that unless the load on the transformers was decreased trouble would again be probable in the hot summer months.

POWER-FACTOR CORRECTION

In the fall of 1925 the Kansas City Power & Light Company offered this consumer a contract with a power-factor clause whereby it would receive a lower rate if the power-factor were held near 100 per cent. It, therefore, became advantageous to consider power-factor correction both due to this and due to the over-loaded condition of the transformers. At this time also the management decided to install another air compressor estimating its demand to be 150 Kw. and a report was therefore made as follows:

If a 1000-kv-a. synchronous condenser were floated on the line connected to the system at the center of gravity, which is at the main switchboard, the load would be brought down to the capacity of the transformers.

If, however, another compressor were added, having an input of approximately 150 Kw., the load would be increased sufficiently that even with this added power-factor correction, the transformers would be 7 per cent over-loaded. This, on the other hand, would not be dangerous but would not allow the addition of any more actual power load.

The load on the lines from the transformers to the switchboard was at a dangerous point last summer and a synchronous condenser installed would increase the load on them.

The above report gave a statement of the condition which would not be changed electrically even if the synchronous condenser and new compressor motor were combined in one machine. A comparison of costs between a separate condenser and a separate motor driven compressor as compared to a combination might be the deciding factor, but it should here be noted that there is a minimum time under the power agreement that the power-factor can increase due to a shut down of the condenser. Therefore, if the compressor were connected to the condenser there would be a chance of a shut down due to the failure of the compressor which would not occur if the condenser floated by itself. On the other had, if the mechanical connection between the condenser and compressor were of a type that could be quickly disconnected, the combination might still prove to be the more efficient.

VOLTAGE REGULATION

In 1921 a test was made on the transformers to determine the voltage regulation. It was found to be 7½ per cent from no load to the full operating load. The manufacturer guaranteed 3.8 per cent at normal load and 80 per cent power-factor. Therefore, this poorer regulation was due to the low operating power-factor and the over-load of the transformers. When the transformer substation was rebuilt the regulation came within the guarantee. A test was also made at the ends of the different distributing lines only to find that the voltage drops between these points and the switchboard were practically negligible reaching a maximum of 15 volts, or slightly more than 3 per cent. This is reasonable and is caused only by the long line and not by line over-load.

ECONOMIC FACTORS

During these tests many interesting points arose. One was the maximum demand. It was realized that no change could be made on this without an actual change in the time and use of energy in the plant. This plant was operating under a system that had obtained for twelve years wherein the cupolas ran only during the middle of the day and, incidentally, during the time of maximum demand.

Large Casting Foundry Load

It was realized that the system had to be changed in the foundry if a saving in demand was to be made in the energy used in the cupolas. The system of foundry operation was to lay the cores and moulds in the sand, starting the cupola up late in the morning, and pour through the middle of the day. The castings first poured were removed from the sand in the early afternoon allowing all castings to be removed by closing time. A night gang of laborers then came in and arranged the sand for the next days moulding. A system was worked out, and is now in operation, whereby the castings, approximately 1500 pounds in weight, are poured as soon as the cupola is operating at the beginning of the morning. This operation continues uninterrupted until evening. This has made a great change in the foundry practice in that the space now occupied for the making of these castings is less than 50 per cent of the original area required. The load on the motor of the cupola, which previously showed 47 Kw. input during its short run, was changed to 10 Kw. for the whole day.

Compressed Air System Load

In 1921 the air compressor equipment consisted of four compressors: One driven by a 100 horse-power motor; one by a 150 horse-power motor and two by one 50 horse-power motor each. This compressed air system as described had a demand of 277 Kw. or 47 per cent of the total load. When the tests were first started a great deal of difficulty was experienced in holding sufficient air pressure during the peak load of the day. However, this was principally due to leaks in the system and when this effect was explained to the management it immediately took steps to repair the system. One hoist, that required abnormally high pressure for its operation, was replaced so that the operating pressure could be decreased. After this had been done it was found that one of the small compressors could be shut down during the entire day thereby decreasing this portion of the demand 45 Kw. or 16 per cent. This system operated thus for some time until changes were made in the foundry which require more compressed air power at which time a new compressor was added. It was found by tests that the cut-off of one of the larger compressors was set at the lowest stage of the group so that its cut-off pressure was frequently reached. A graph of the wattmeter chart taken on this motor during the critical pressure period is shown in Graph number 5. This unstable operation of a large machine is unadvisable and, therefore, cut-offs were adjusted so that now the small compressors float on and off during the critical period. This change did not cause any noticeable power saving but it did improve the power-factor because the larger motor that cut-out was of a slip-ring type of induction motor which, when operated in the low load condition, was an appreciable handicap on the power-factor.

An attempt has been made to consider electrical hoisting equipment but compressed air has been used throughout all the factories of this company and, therefore, all of their machines are equipped to use compressed air whenever and wherever possible, therefore, it is probable that air compressor equipment will be added from time to time with the gradual change from manual to mechanical operation of the factory.

A tabulation of various calculations is given below.

The connected horse-power is based on motors of a continuous rating of 50 degrees centigrade rise. There are some motors of continuous rating of 40 degrees centigrade rise capable of carrying 25 per cent over-load two hours with a temperature rise not to exceed 55 degrees centigrade. These motors are given a 20 per cent increase in rating to place them on a 50 degree centigrade rise basis. This practice is standard among manufacturers. The connected K.W. is based on an average efficiency of 87 per cent. Total kilowatt-hours and total demand information was obtained from the meter reading records of the Kansas City Power & Light Company. The percentage of the entire load for each division was obtained from the individual loads of the motors, but the air system load was prorated between the two divisions in proportion to the air using equipment. The percentages thus determined were applied to the kilowatt-hours consumption for the month and therefore the kilowatt-hours/gross ton were calculated.

	SEPTEMBER 1921	DECEMBER 1922	DECEMBER 1925
Connected H.P.	1540	1477	1639
Connected K.W.	1320	1270	1420
Maximum Demand	584	691	921
Average Kw. per Hour	240	395	493

	SEPTEMBER 1921	DECEMBER 1922	DECEMBER 1925
Load Factor	41%	57%	54%
Demand Factor	44%	55%	65%
Connected Load Factor	18%	31%	35%
Gross Ton, Large Casting	1774	1961	1590
Gross Ton, Small Casting	1759	2080	2120
Gross Ton, Total	3503	3969	3710
Kw-hrs/Gross Ton, Large Casting	77.5	100	176
Kw-hrs/Gross Ton, Small Casting	37.7	42	35.4
Kw-hrs/Gross Ton, Total	55.5	71.5	95

The only available statistics on the economic factors of this type are listed below, being taken from a paper presented in 1909 by E. W. Lloyd, before the National Electric Light Association. These figures were obtained from tests made in Chicago.

	LOAD FACTOR	DEMAND FACTOR	CONNECTED LOAD FACTOR
Foundries	15%	75%	11%
Machine Shops	26%	55%	14%

It will be noted that all of the economic factors compare very favorably with Mr. Lloyd's values; also that all of these factors were greatly improved during these investigations; it was ever in mind to load the motors to their maximum values and to change the time of the loading to reach a minimum maximum demand.

In 1921 it was estimated, and reported to the management, that the maximum demand factor that could be expected in a factory of this type, from a practical standpoint, would be 68 per cent and this compares very favorably with the 65 per cent reached in 1925.

In 1922 the decrease in connected horse-power of the under-loaded motors and the increase in motors installed in the Large Casting division increased the demand factor. But, in 1925 the connected horse-power had reached a maximum degree of efficiency which gave this 65 per cent demand factor. A typical demand meter chart is shown on Graph number 6.

It will be noted that the kilowatt-hours per gross ton have increased, but also it will be noted that this increase was due to the Large Casting division and it was due entirely to the changing from manual to mechanical operation in the foundry. It was due to the Large Casting foundry alone that the increase was called for in the air compressor system and that new sand mixing machines were added.

CONCLUSIONS

The operating improvements resulting from an investigation of this type may be listed as follows:

A saving was made in electrical power used, the ratio of mechanical to manual operation of the plant not varying. This was occasioned by the decrease in maximum demand and by the removal of many horse-power in motors, which decreased the no load losses in the system.

A decrease was made in the actual installed investment and depreciation of the same under operation.

The system is gradually being reconstructed to minimize the different hazards, i.e., life, fire, and service failures.

Motors of correct types are being installed with protective apparatus applicable to the load.

The management understands the situation and does not hesitate to change from manual to mechanical operation wherever possible. This result is producing improvements in factory and foundry practices.

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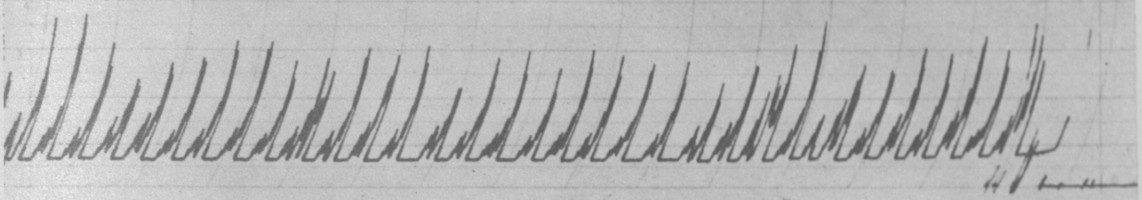
THE ESTERLINE COMPANY. CHART
INDIANAPOLIS, IND. U.S.A. No. 2310-C

Graph Number 1

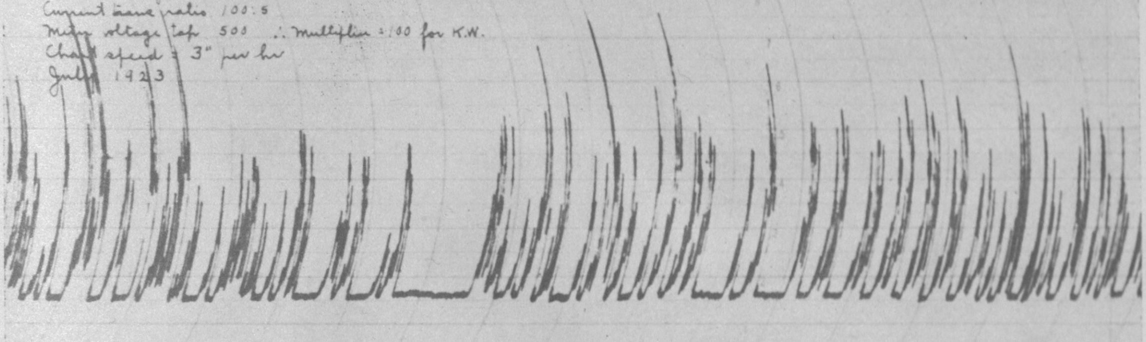
One Surface Grinding Machine
Motor G.E. Type I-50hp-514 RPM
Current trans ratio 100:5
Meter voltage tap 500 ∴ Multiplier = 100 for KW
July 1-1921

Machine operating on light load
test on other machine shows peaks of 68 KW



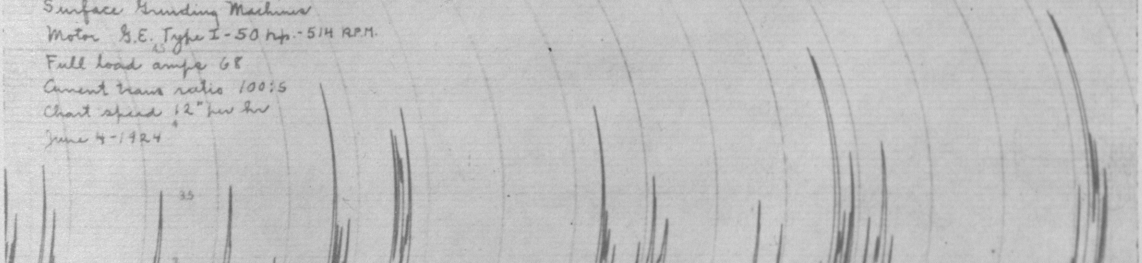
Graph Number 2

Surface Grinding Machine
Motor G.E. Type I - 50 hp - 514 RPM
Current trans ratio 100:5
Meter voltage tap 500 ∴ Multiplier = 100 for K.W.
Chart speed = 3" per hr
July 1923

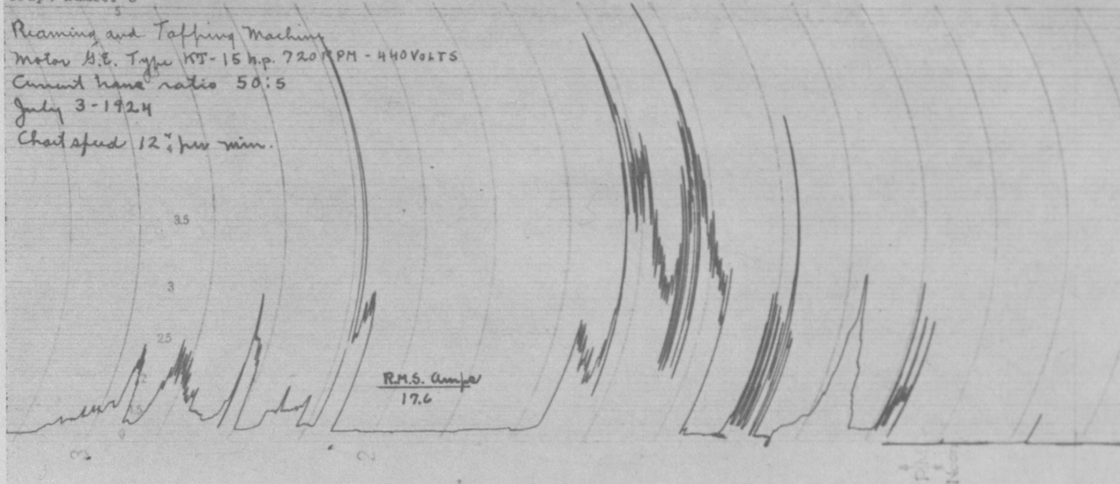


Graph Number 2-a

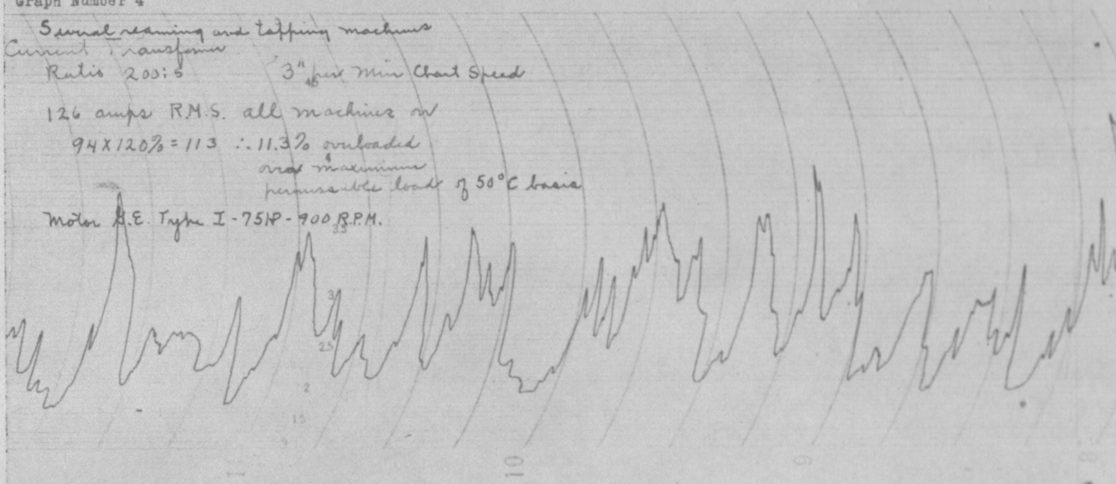
Surface Grinding Machine
Motor G.E. Type I - 50 hp. - 514 R.P.M.
Full load amps 68
Current trans ratio 100:5
Chart speed 12" per hr
June 4-1924



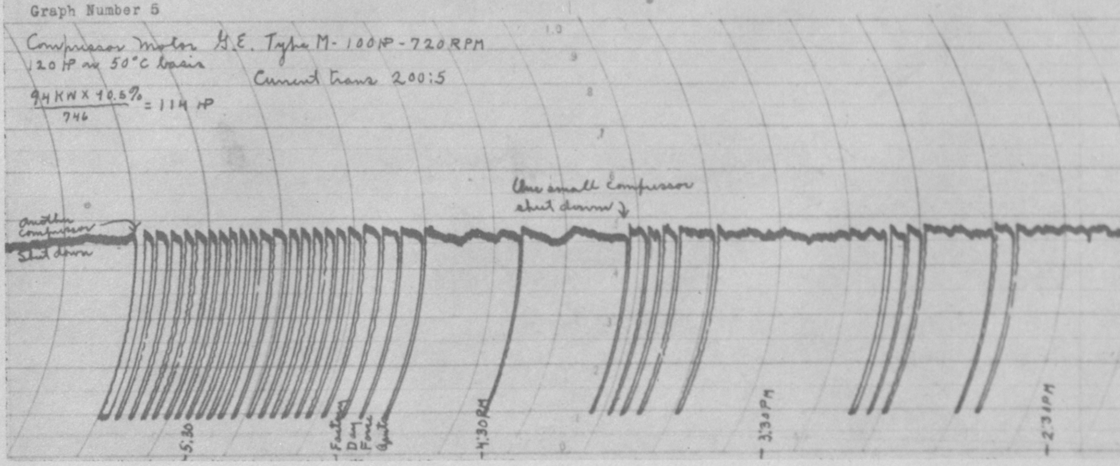
Graph Number 3

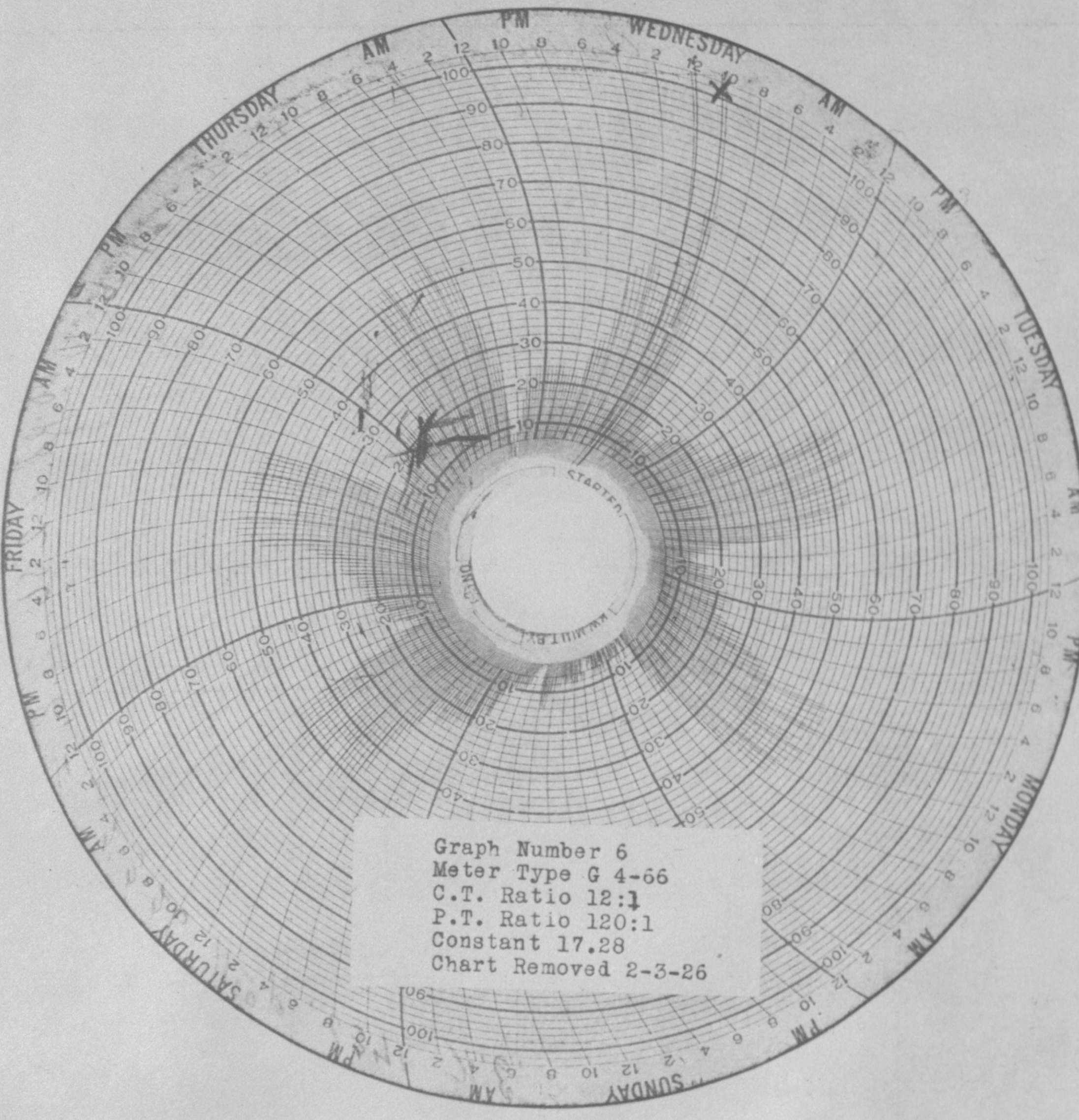


Graph Number 4



Graph Number 5




Graph Number 6
Meter Type G 4-66
C.T. Ratio 12:1
P.T. Ratio 120:1
Constant 17.28
Chart Removed 2-3-26
WEDNESDAY
THURSDAY
FRIDAY
SATURDAY
SUNDAY
MONDAY
TUESDAY