Greves & Wood

An Analysis of Induction Motor Applications

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AN ANALYSIS OF INDUCTION MOTOR APPLICATIONS

BY

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THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

George Lowthane Greves and Daniel Charles Wood

ENTITLED An Analysis of Induction Motor Applications

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

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AN ANALYSIS OF INDUCTION MOTOR APPLICATIONS.

I

INTRODUCTION.

The ever increasing demand in the commercial field for the electrically driven machine has necessitated the study of various types of motors in actual operation. It is the purpose of this thesis to study the field of motor operation which is limited to the polyphase induction motor, to analyze this motor thoroughly, and to point out its merits and demerits from the consumers point of view as well as from the standpoint of the Central station. Furthermore, it is the purpose to show the efficiency of the system may be increased and the regulation of the line benefited by the proper choice of motors. It was with this aim in view that the data compiled in this thesis was taken by the engineering department of the Peoria Gas & Electric Co.

II

GENERAL DISCUSSION

A. THE CENTRAL STATION AND THE DISTRIBUTING SYSTEM.

Experience has proven that power may be produced more economically by one large station than by a number of small ones. It is for this reason and the additional fact that continuity of service is better assured, that the large central station has come into general use. On the other hand, the consumers are scattered over a large territory and this necessitates the transmission of power for long distances. To avoid excessive line losses the power should be transmitted at high voltages, and the ease with which alternating current may be handled makes it especially desirable. Three phase current is used because of the advantages of the polyphase motor and because of the economy of copper in the construction of line for transmitting polyphase current.

In the early history of the central station the power generated was used almost entirely for lighting purposes, this making the heavy load come for a short time during the evening, with practically no load during the remainder of the twenty-four hours. Therefore, the load factor was quite low for such a station carrying only a lighting load. However, by the introduction of the motor the load factor is raised. Since the power consumer will as a rule draw current from the line at a time when the lighting load is small and as the power and lighting loads overlap very little the same generators may be used for both purposes. Hence without the addition of new

machinery the kilowatt output of the plant may be greatly increased. The maximum economy of the station is for the machines working close to their rated capacity, and it is for this reason that many companies make it a policy to sell power used during the light load hours at a low rate.

B. TYPES OF LOADS.

Loads which motors are required to carry may be classified as follows:-

1st. Steady loads:- This is as the name indicates a load which requires a steady torque while running. For starting it may or may not require a high torque. In general those loads having heavy revolving parts require a large starting torque.

2nd. Pulsating loads:- Under this head may be put loads such as the reciprocating pump, or where a sudden increase of power is required at certain definite intervals of time.

3d. Intermittent loads:- When the machine is started and stopped very often or when the load is applied at irregular intervals the load is intermittent.

C. MOTORS AVAILABLE AND THEIR CHARACTERISTICS.

In the following discussion the direct current motor is not considered since the high voltage required for economical power distribution eliminates this type. Of the alternating current motors the synchronous motor is not convenient since it requires more care and knowledge to operate it than is possessed by the ordinary workman. Also the starting torque is very low so that it can not be started under load. Another objection is that it requires a direct current generator to supply field current, and that together with other features of the construction makes the synchronous motor more expensive than the induction type. It is a very desirable load for a central station since it may be operated at unity or a leading power factor and thus used to improve the lagging power of the system.

The other motor available is the polyphase induction motor which may have the squirrel cage style of rotor or a variable resistance rotor. The two types have different characteristics although the equations are the same.

The efficiency of the motor is defined as $\frac{\text{output}}{\text{output} + \text{losses}}$. The losses are core loss, windage and friction and I^2R losses. The core loss increases with the volume of the iron used and with the 1.6 power of the maximum flux density. If the motor is used with a higher impressed voltage the iron losses are increased. From the I^2R losses

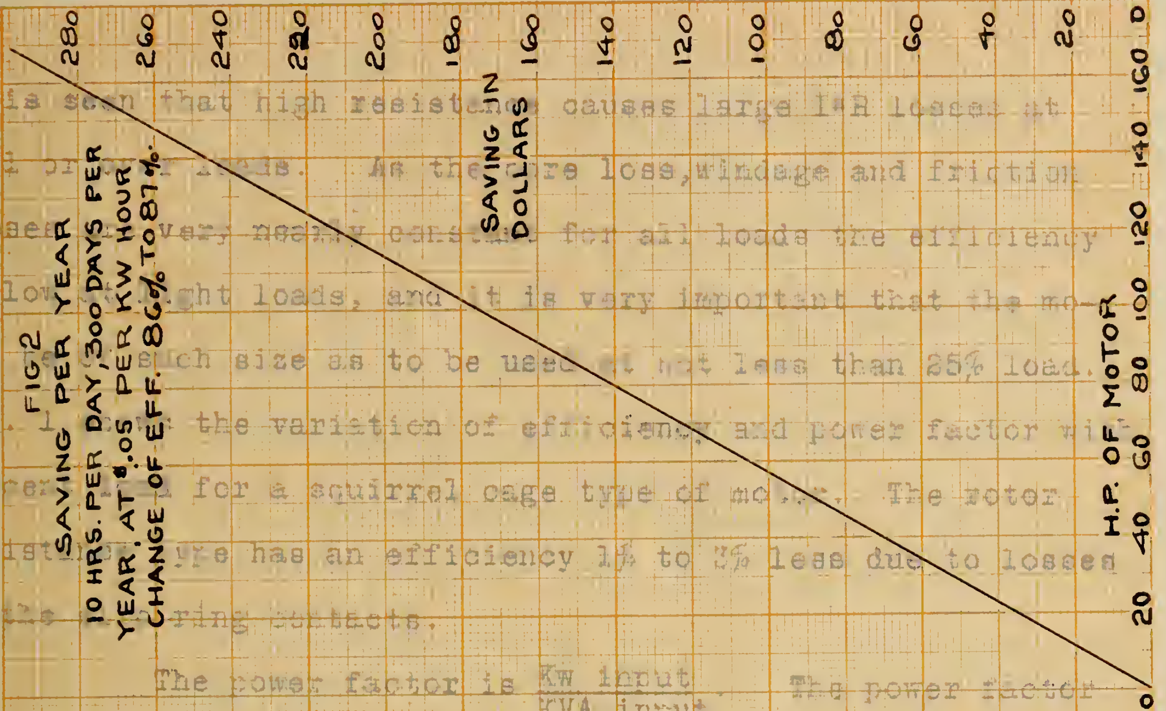

FIG 2
SAVING PER YEAR
10 HRS. PER DAY, 300 DAYS PER YEAR, AT $.05 PER KW HOUR
CHANGE OF EFF. 86% TO 87%.

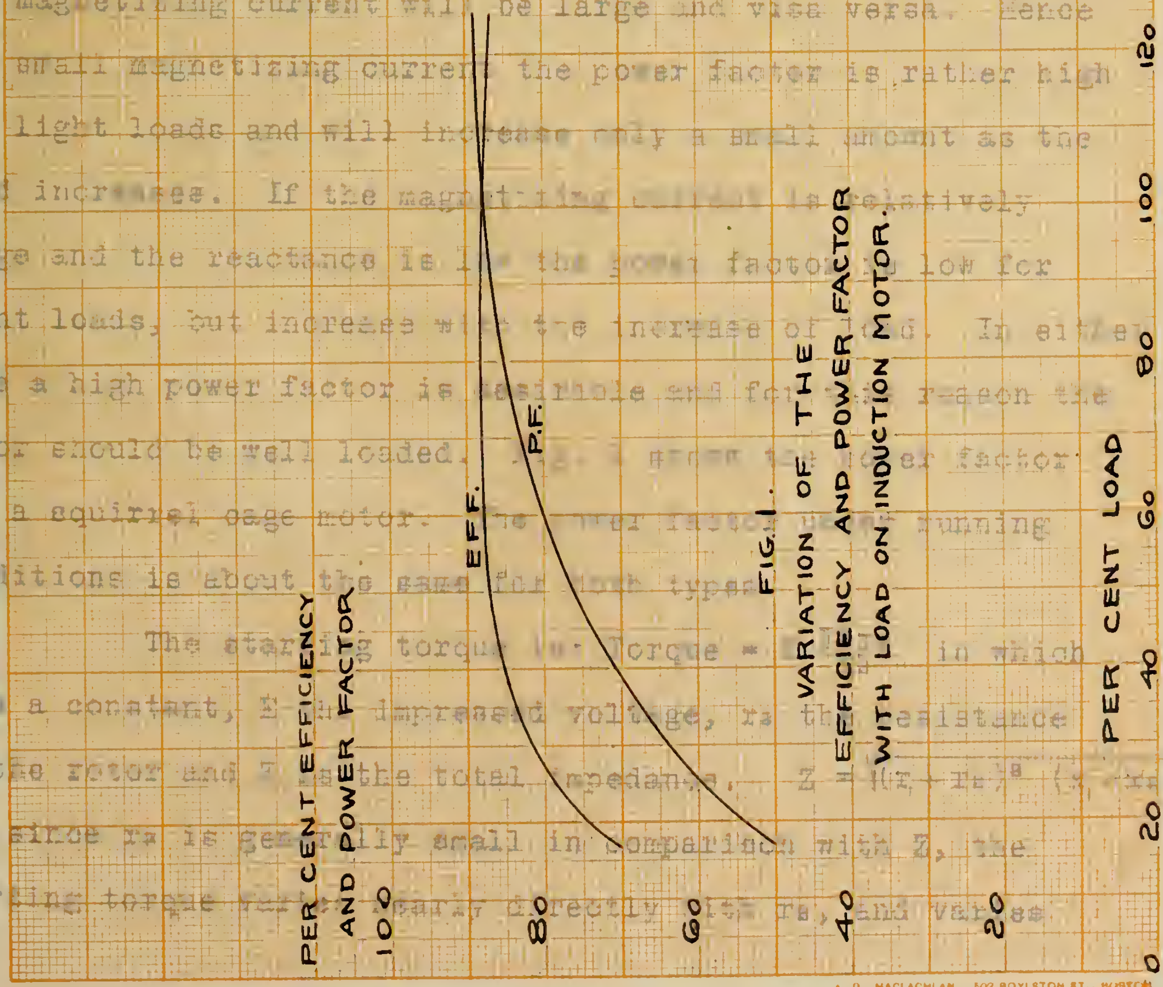

FIG. 1. VARIATION OF THE EFFICIENCY AND POWER FACTOR WITH LOAD ON INDUCTION MOTOR.

it is seen that high resistance causes large I^2R losses at full or over loads. As the core loss,windage and friction losses are very nearly constant for all loads the efficiency is low at light loads, and it is very important that the motor be of such size as to be used at not less than 25% load. Fig. 1 shows the variation of efficiency and power factor with percent load for a squirrel cage type of motor. The rotor resistance type has an efficiency 1% to 3% less due to losses at the slip ring contacts.

The power factor is $\frac{\text{Kw input}}{\text{KVA input}}$. The power factor is affected by the magnetizing current which is wattless, and by the reactance drop. In general if the reactance is low the magnetizing current will be large and visa versa. Hence for small magnetizing current the power factor is rather high for light loads and will increase only a small amount as the load increases. If the magnetizing current is relatively large and the reactance is low the power factor is low for light loads, but increase with the increase of load. In either case a high power factor is desirable and for this reason the motor should be well loaded. Fig. 1 shows the power factor for a squirrel cage motor. The power factor under running conditions is about the same for both types.

The starting torque is: Torque $= K \frac{E^2 r_2}{Z^2}$ in which K is a constant, E the impressed voltage, r_2 the resistance of the rotor and Z is the total impedance. $Z = \sqrt{(r_1 + r_2)^2 \quad (x_1 + x_2)^2}$ and since r_2 is generally small in comparison with Z, the starting torque varies nearly directly with r_2, and varies

directly with E^2. Fig. 3 shows the variation of percent torque and current with percent of synchronous speed for primary and secondary control. It is interesting to note that using any one of the methods the results are the same for torque and current speed for the third point. This indicates that the rotor resistance is the same as that of the squirrel cage rotor. By cutting out the remaining resistance this particular motor will give 270% full load torque with a speed variation of 10% from synchronous speed. Figure 4 gives similar curves for 1-30 H.P. rotor resistance motors, and Fig. 5 curves for 3/4 - 7 1/2 H.P. squirrel cage type motors. Both are for General Electric Company machines. In the list of data tabulated later in this thesis are a number of tests of the Westinghouse Electric and Manufacturing Company Type H.F. motors. These have a rotor resistance with thirteen divisions. With this numberof resistances the motor may be brought up to speed under full load torque without increase of current beyond that required for starting.

It is interesting at this time to note the effect of variation of voltage on the operation of the inductor motor. It will be noted by reference to Fig. 6 that at full rated output and 115% voltage the torque and efficiency are about the same, while the current and percent slip are less. The power factor is considerably less indicating that while less current is required a large proportion of it is magnetizing. It will be noted that the breakdown torque is increased by about 25% with this increase of voltage.

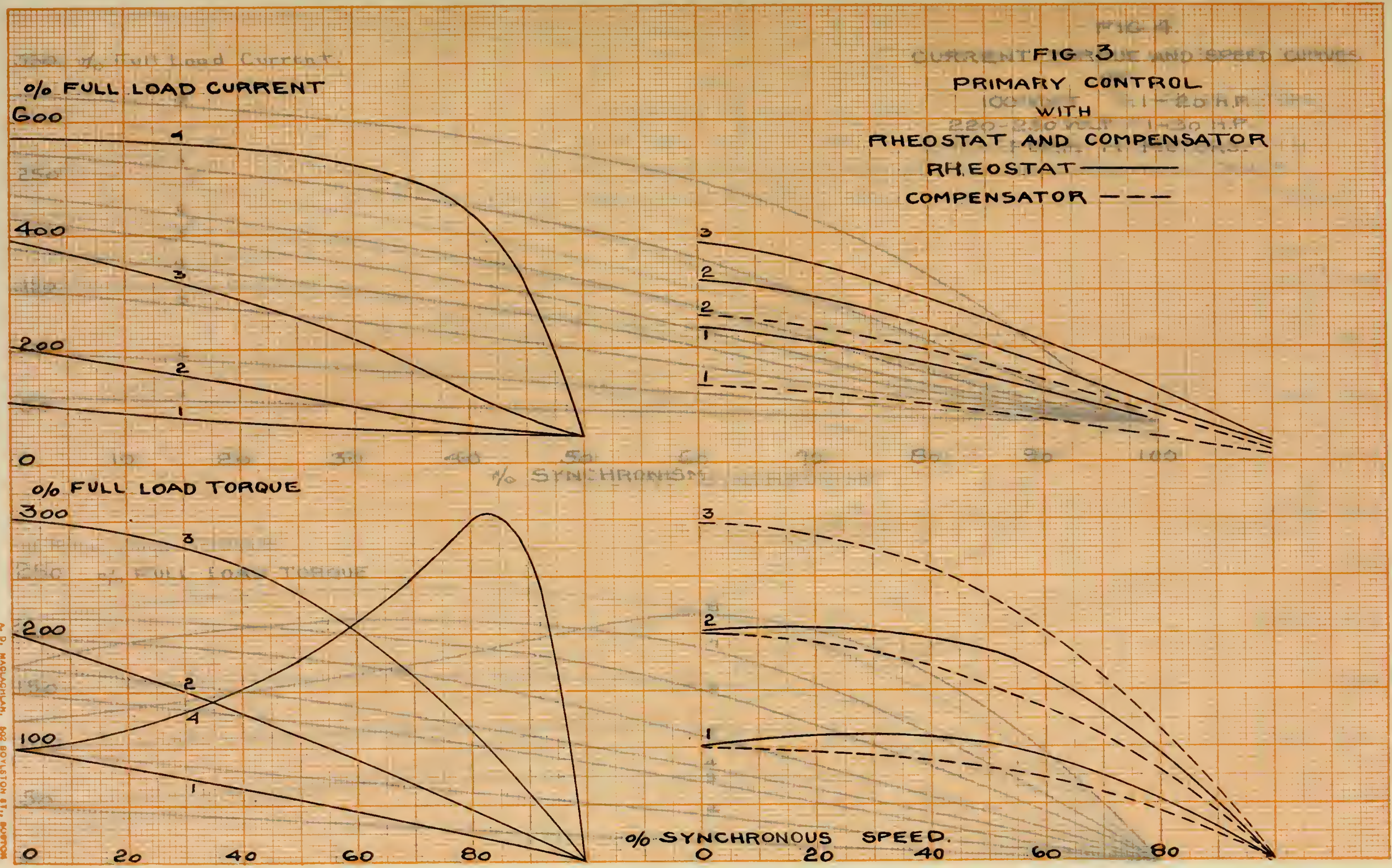

FIG 3

PRIMARY CONTROL

WITH

RHEOSTAT AND COMPENSATOR

RHEOSTAT ———

COMPENSATOR - - -

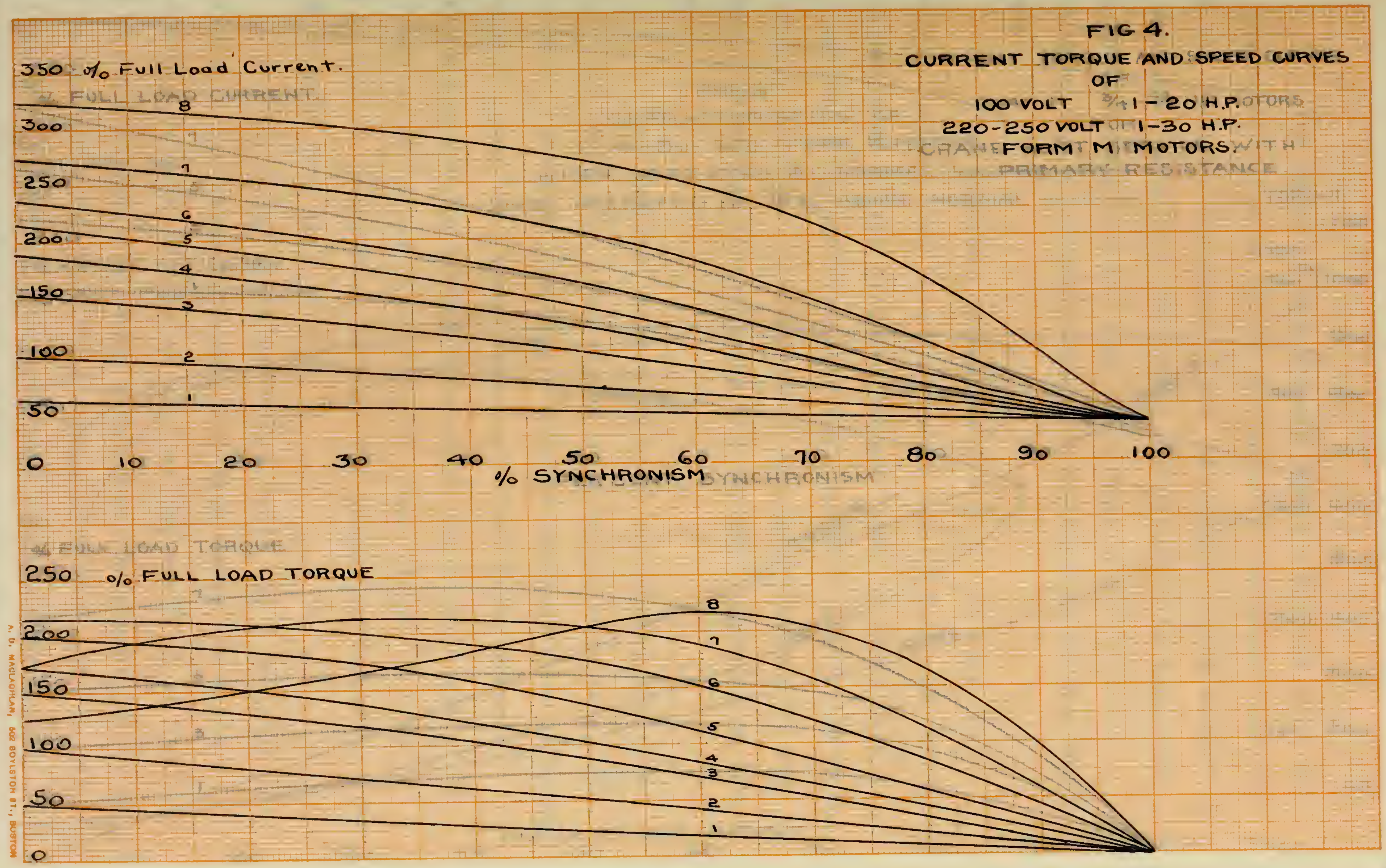

FIG 4.

CURRENT TORQUE AND SPEED CURVES
OF
100 VOLT 1 - 20 H.P.
220-250 VOLT 1-30 H.P.
FORM M MOTORS.

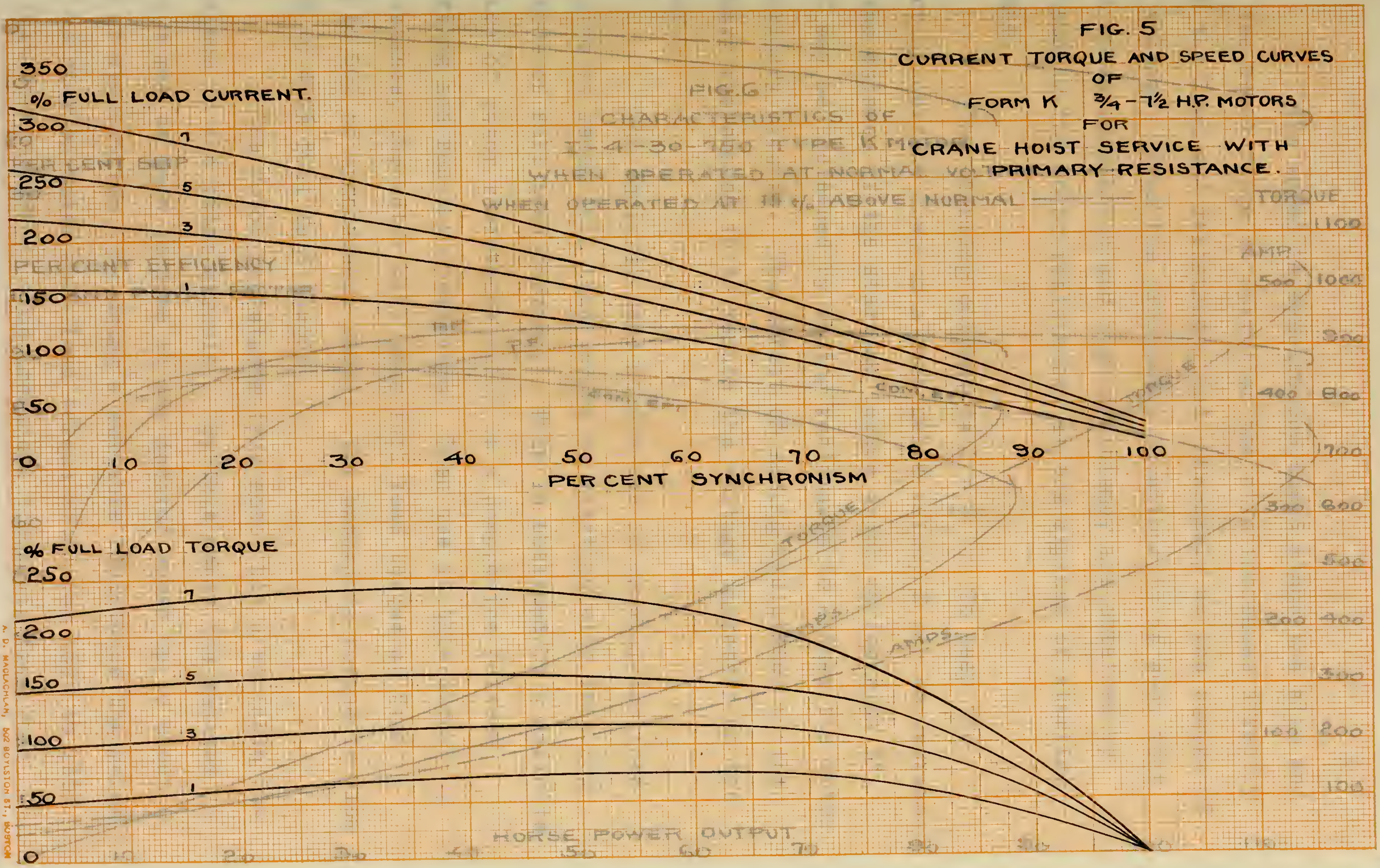

FIG. 5

CURRENT TORQUE AND SPEED CURVES
OF
FORM K 3/4 - 7 1/2 H.P. MOTORS
FOR
CRANE HOIST SERVICE WITH
PRIMARY RESISTANCE.

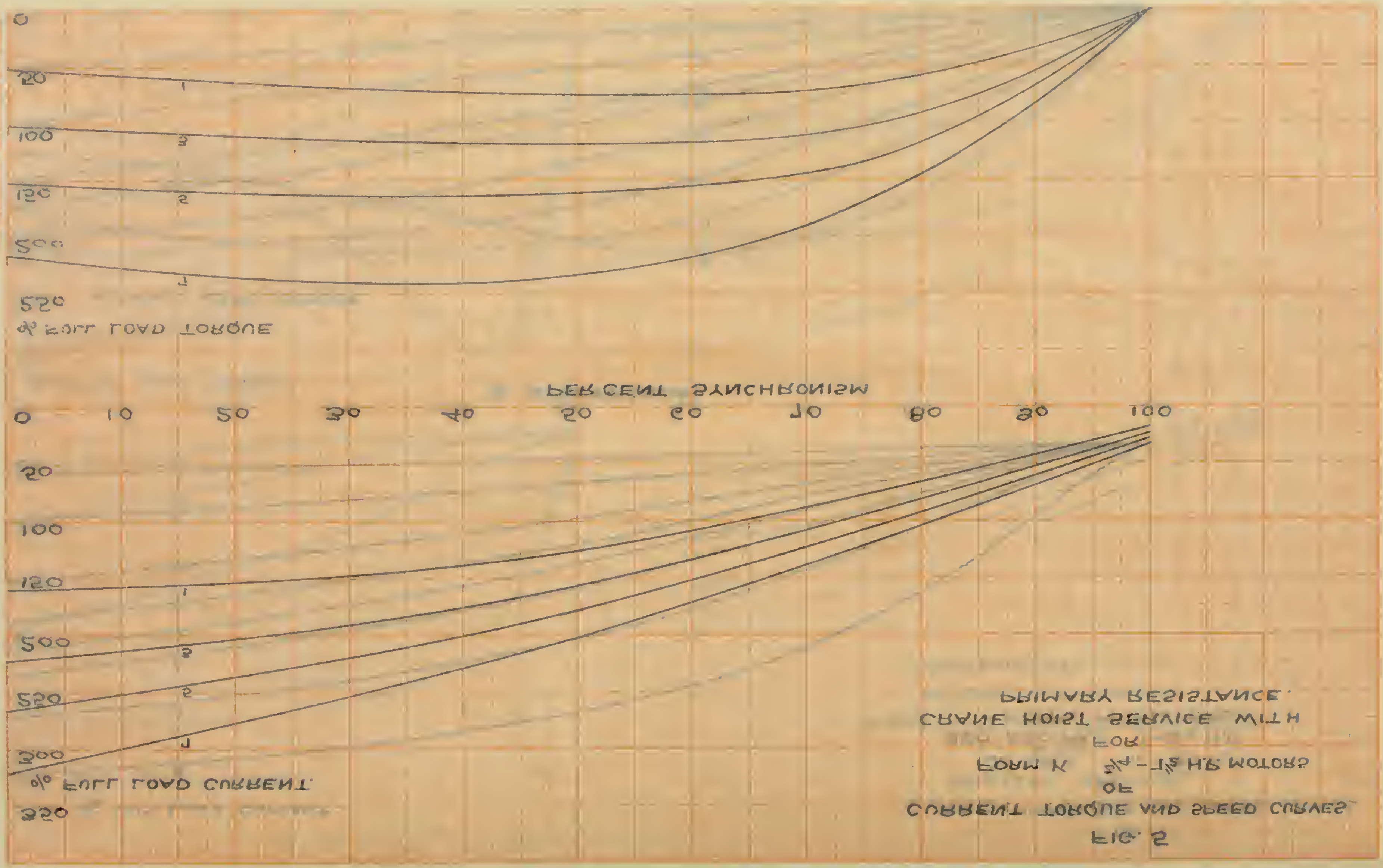

FIG. 5

CURRENT TORQUE AND SPEED CURVES
OF
FORM K 3/4 - 1½ H.P. MOTORS
FOR
CRANE HOIST SERVICE WITH
PRIMARY RESISTANCE.

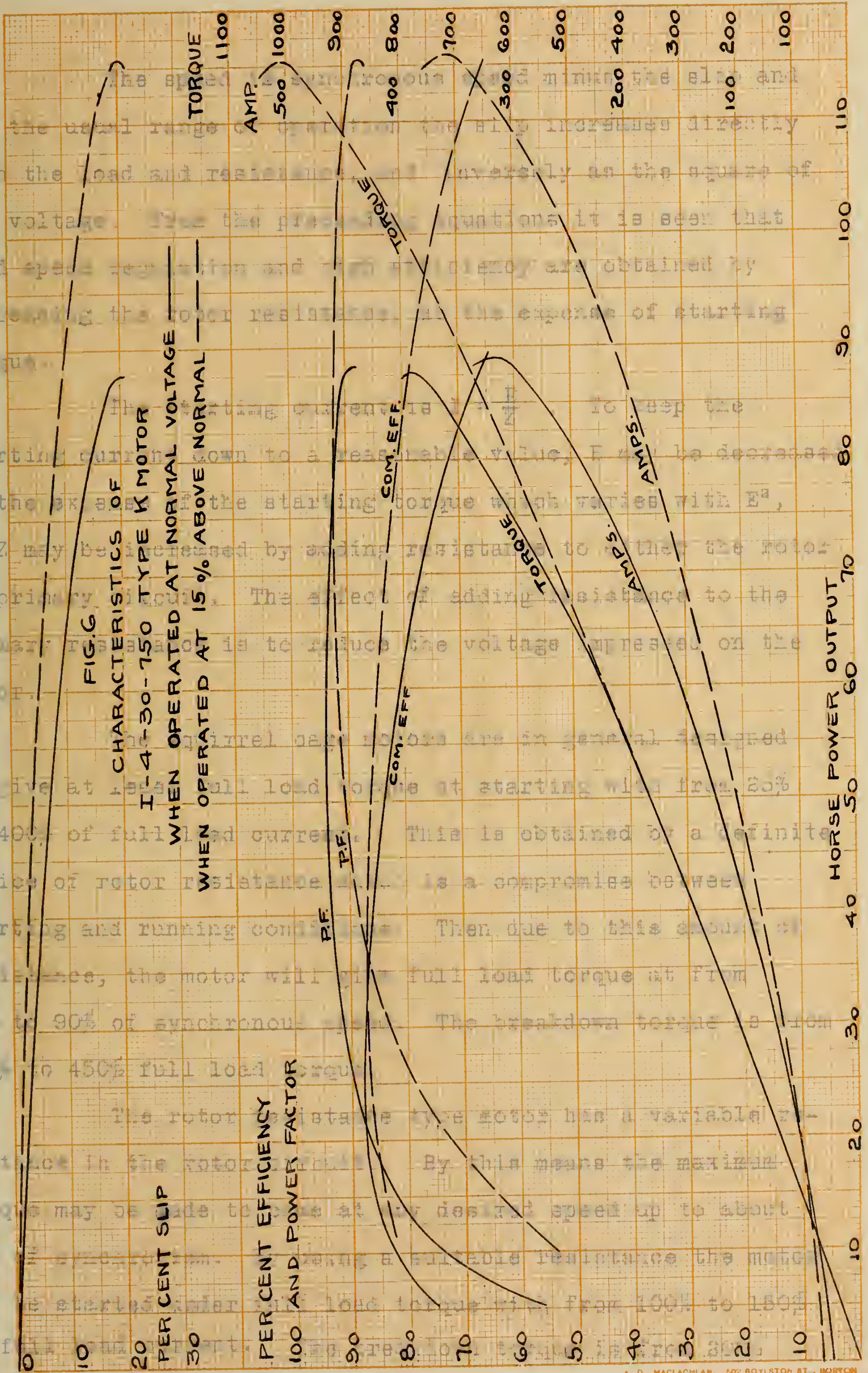

FIG. G

CHARACTERISTICS OF I-4-30-750 TYPE K MOTOR

WHEN OPERATED AT NORMAL VOLTAGE ———

WHEN OPERATED AT 15% ABOVE NORMAL — — —

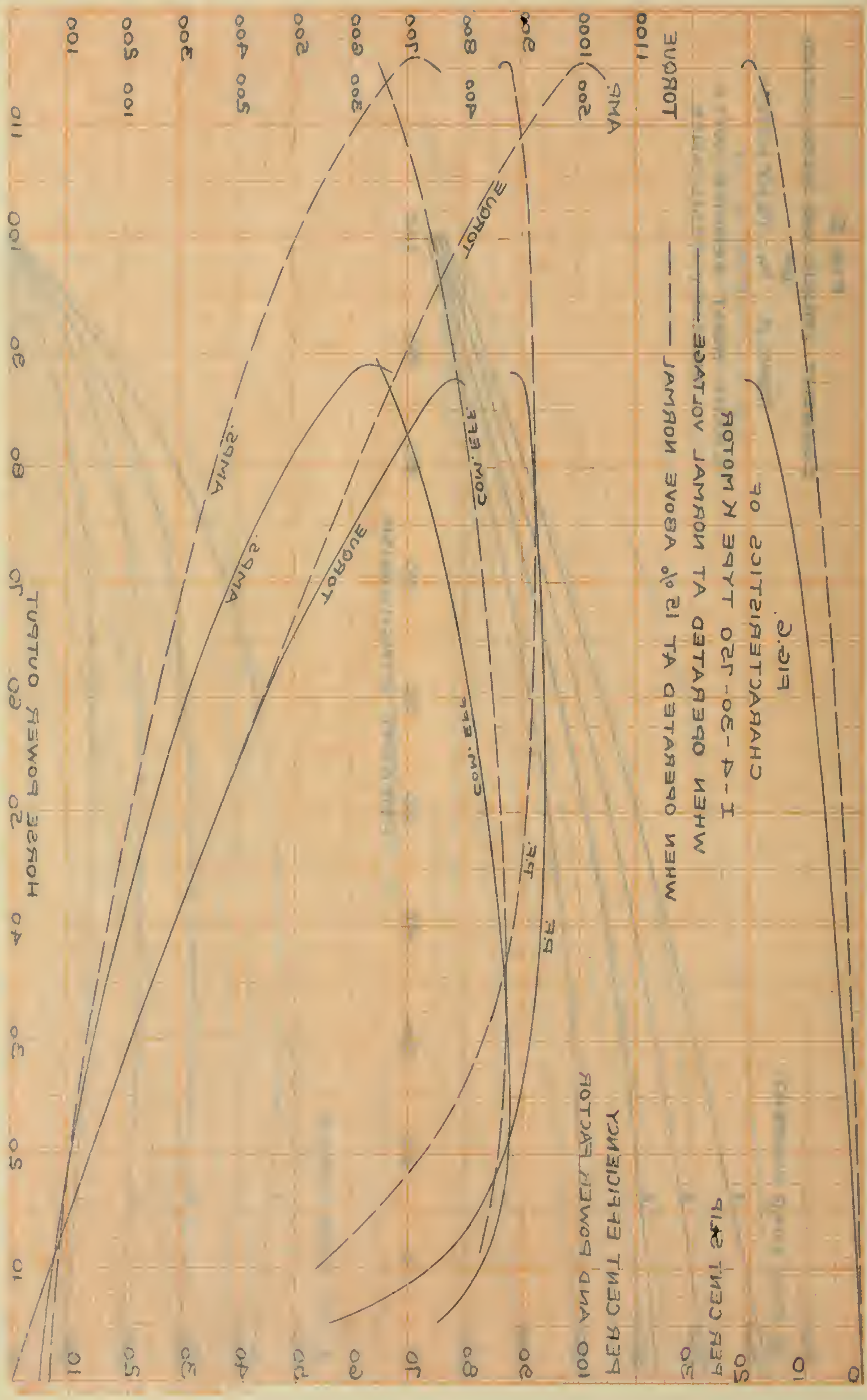

FIG. 6

CHARACTERISTICS OF
I-4-30-150 TYPE K MOTOR
WHEN OPERATED AT NORMAL VOLTAGE ———
WHEN OPERATED AT 15% ABOVE NORMAL — — —

The speed is synchronous speed minus the slip and for the usual range of operation the slip increases directly with the load and resistance, and inversely as the square of the voltage. From the preceeding equations it is seen that good speed regulation and high efficiency are obtained by decreasing the rotor resistance, at the expense of starting torque.

The starting current is $I = \frac{E}{Z}$. To keep the starting current down to a reasonable value, E may be decreased at the expense of the starting torque which varies with E^2, or Z may be increased by adding resistance to either the rotor or primary circuit. The effect of adding resistance to the primary resistance is to reduce the voltage impressed on the motor.

The squirrel cage motors are in general designed to give at least full load torque at starting with from 25% to 400% of full load current. This is obtained by a definite choice of rotor resistance which is a compromise between starting and running conditions. Then due to this amount of resistance, the motor will give full load torque at from 80% to 90% of synchronous speed. The breakdown torque is from 200% to 450% full load torque.

The rotor resistance type motor has a variable resistance in the rotor circuit. By this means the maximum torque may be made to come at any desired speed up to about 90% of synchronism. By using a suitable resistance the motor may be started under full load torque with from 100% to 150% of full load current. The breakdown torque is from 200%

to 350% of full load torque.

D. THE FUNCTIONS OF AN ENGINEERING DEPARTMENT.

The interest of the consumer centers in the following points. The motor must be able to start and run under full load, and it must be able to stand up well under heavy overloads for a short time. It must be simple enough for the ordinary workman to operate and it must stand hard usage and abuse. Finally the motor must be efficient. The starting current is of interest to the consumer if his own lighting circuit is affected as evidenced by the flicker of the lights when the motor starts. Also if the motor accelerates slowly and a heavy starting current continues over a considerable interval of time, large wires are required. In some cases a given speed regulation is required, but for most industrial machines the regulation is satisfactory for any load that the motor may have to carry.

The central station engineer is responsible for the maintenance of satisfactory service for power and lighting loads, and at the same time is responsible to his employer for the economical operation of the system. To give proper service the generators must have a large enough Kva. capacity to carry the loads without heating. When the load is inductive as is the case when induction motors are used, the kilowatt output of the generator is decreased. Fig.7 shows the percent

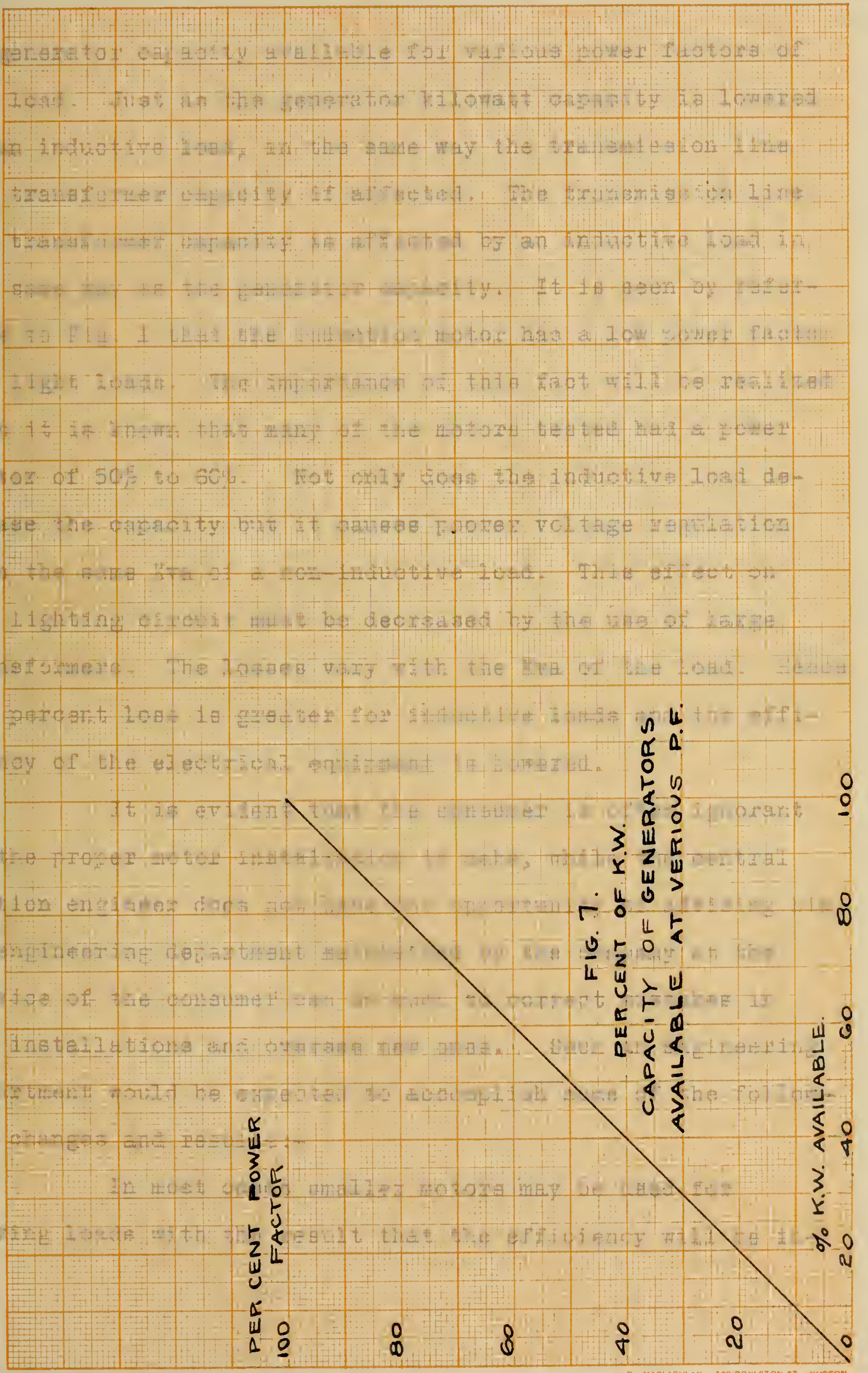

FIG. 7.
PER CENT OF K.W. CAPACITY OF GENERATORS AVAILABLE AT VERIOUS P.F.

of generator capacity available for various power factors of the load. Just as the generator kilowatt capacity is lowered by an inductive load, in the same way the transmission line and transformer capacity if affected. The transmission line and transformer capacity is affected by an inductive load in the same way as the generator capacity. It is seen by reference to Fig. 1 that the induction motor has a low power factor for light loads. The importance of this fact will be realized when it is known that many of the motors tested had a power factor of 50% to 60%. Not only does the inductive load decrease the capacity but it causes poorer voltage regulation than the same Kva of a non-inductive load. This effect on the lighting circuit must be decreased by the use of large transformers. The losses vary with the Kva of the load. Hence the percent loss is greater for inductive loads and the efficiency of the electrical equipment is lowered.

It is evident that the consumer is often ignorant of the proper motor installation to make, while the central station engineer does not have the opportunity of advising him. An engineering department maintained by the company at the service of the consumer can do much to correct mistakes in old installations and oversee new ones. Such an engineering department would be expected to accomplish some of the following changes and results:-

In most cases smaller motors may be used for driving loads with the result that the efficiency will be in-

creased and the cost of power to the consumer lowered. By this same means, the power factor of the motors is raised, more generator capacity is made avilable and the line drop is decreased.

For some conditions large squirrel cage motors have had to be installed to start the load. These may be changed for smaller motors having rotor resistances, or a friction clutch may be provided to throw the load on the squirrel cage motors after they come up to speed. Where possible the latter plan is better since the squirrel cage motor has higher efficiency. Thus a load requiring a high starting torque may be started without excessive flow of current. This is an improvement for both the consumer and central station engineer. A countershaft and pulley is not advised since the increased efficiency of the smallermotor is lost by the lower belt efficiency.

A third way in which this engineering department may help the consumer is by giving assistance in regrouping to the best advantage the machines that are to be run by one motor.

III

METHOD AND DESCRIPTION OF TESTS.

The tests used in this thesis were made by the engineering department of the Peoria Gas and Electric Co. The purpose of the test was not only to investigate the present conditions, but to collect data on all available types of machines, so that the sales department could sell the proper motors for new installations.

The motors were tested under every condition of loading possible to obtain, also for running light and starting. Since it is the normal running load and starting torque which determine the size and type of the motor necessary, only these tests will be given and discussed. The readings taken were; power by two wattmeter method, current, voltage and speed.

In making the tests it was often necessary to meter large currents. To avoid the use of ammeters of excessive range, split core current transformers were used. The compensating coils on the watt meters were not used. All instruments were calibrated with precision meters, the property of the company. Curves were plotted from these calibrations and the reading taken in the tests were corrected from these curves.

Some of the instruments were not dead beat and in getting the starting current and power, the needles would swing considerably past their correct reading, due to the

sudden rush of current. To overcome this difficulty the readings were corrected from a curve plotted between true reading and first swing of instrument.

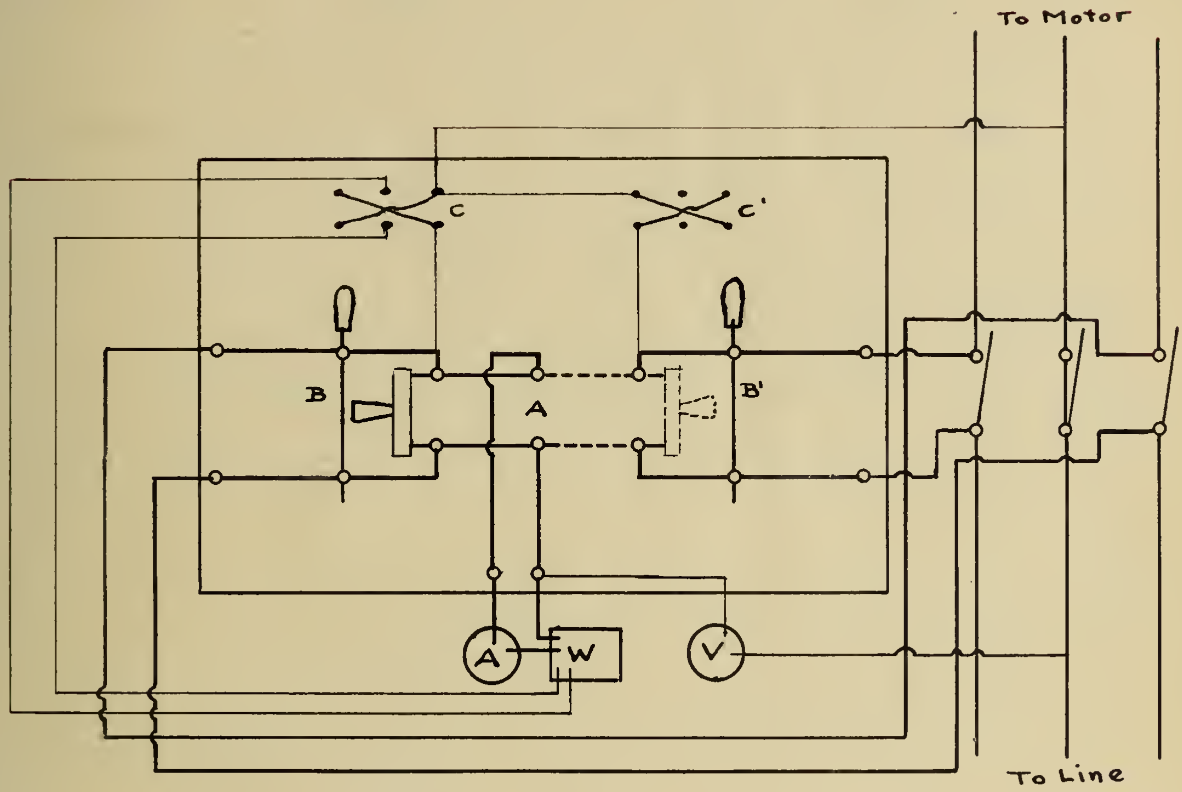

FIGURE 8

To avoid the necessity of carrying a large number of instruments long distances a board such as shown in Figure # 8 was used. The switch B is a large double throw double pole switch, the end connections of which are joined to the single throw knife switches A and A'. The connections are made from these connections to the line as shown in the diagram. In place of the two wattmeter method of measuring power all readings may be taken on one set of instruments by the proper manipulation of the three switches.

This method was used only where the load was steady. C and C' are double throw double pole switches for reversing the current through the pressure coil of the watt meters. This method of reversing the reading of the watt meter was used in preference to changing the current through the current coil because it could be done without in any way interfering with the continuity of service. Every precaution was used to give the consumer continuous service throughout the test with the exception of the interruption necessary to get starting data.

		MOTOR RATING			MACHINE LOADED			MACHINE IDLE			STARTING		
	PUMPS	MAKE TYPE FORM	H.P. VOLTS AMP.	R.P.M.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.
26	Centrifugal Beer Pump, Direct Connected, Load – Raising 165 bbls. Water per Hour 65'.	G.E. Co KT C	5 220 13	1800 R 1840 E 1753 L	2500	1550	.926	720	-10	.488	2800		
					12.1	12.7	5.42	5	5	.95	76	74	
27	Centrifugal Beer Pump, Direct Connected to Filter, Pumps against 27° pressure Starts under no pressure.	G.E. Co. KT. C	2 220 5.7	1200 R	400	540	.968				1230	1700	.947
					3.	3.	1.26				57.7	58.5	3.92
28	Centrifugal Yeast Pump, Direct Connected. Load – Raising 925 Gal. Water per Hr. 15' thru 100' of 2" Hose.	G.E. Co KT C	2 220 5.7	1200 R 1218 E 1210 L	540	30	.539	440	-55	.409	1470	2800	.817
					2.9	2.8	.76	2.6	2.5	.52	27	27.7	5.72
30	Centrifugal Beer Pump, Same as # 27	G.E. Co KT C	3 220 8.4	1200 R	630	400	.932				860	290	.758
					3.5	3.6	1.38				74	74	1.54
40	Water Pump, Direct Connected, Runs at intervals 2/3 of day. Pressure 65#. Starts under Load.	G.E. Co I K	7.5 220 21.5	900 R	880	3700	.684				5100	15000	.76
					12.8	13.7	6.4				92	93	26.9
129	Centrifugal Water Pump, Direct Connected. Raises water 6' thru 2" pipe. No Starter.	Westh. CCL	5 440 6.7	1120 R	2000	1500	.968				3000	1700	.901
					5.2	5.2	4.69				29.	28.5	6.29
	ELEVATORS												
19	Grain Elevator. Load .3 bu. wheat per. min. Raised 80 Feet.	Westinghouse. CCL	5 220 12.7	1700 R 1800 A 1812 L	00	740	.50	-95	560	.332	1300	9500	.614
					4.5	5.	1.0	3.8	5.	.61	58	57	14.5
25	Coal Elevator and Conveyor. Motor will not start under load.	G.E. Co I L	25 220 65.	1200 R 1210 E 1210 L	6000	4800	.982	5200	2500	.852	18000	9500	.88
					29.	27.	14.5	20	20	10.3	76.	76.	36.8
39	Freight Elevator for charging Cupola. Load 800 Pounds. Readings – Going Down.	Westh. F No. 100	5 220 18.9	1120 R	1800	-1200	.122	2800	190	.551	5900	2360	.802
					13.9	14.4	.87	15.4	15.4	4.	40	42	11.1
39	Load same as above. Readings – Elevator Going up.				-375	2480	.392	-800	2050	.282	2150	5770	.786
					13.9	14.4	2.82	13.3	13.3	1.68	40	42	10.6
41	Freight Elevator. 5 Ton Capacity. Load 250#. Readings taken going Down	Otis Elev Company Style 10 AC	15 220 42	900 R	5000	2660	.884				15000	11000	.966
					24	24	10.3				57.	55.5	34.4
41	Same as above Readings taken going up.				-3000	2660	.034				8000	17000	.848
					16	24	-.46				57.	55.	33.5
71	Freight Elevator. 2-3 Ton Capacity. Load about 175 lbs. Readings – elevator going down	Northern Elec. Co	15 220 42	780 R 768 L	-1780	2690	.119				5250	10500	.866
					18.3	13.5	1.22				66	88	21.1
71	Same as above Elevator going up.	O X			8000	-960	.413				12500	5850	.833
					18.3	19.	9.42				92	88	24.6

		MOTOR RATING			MACHINE LOADED			MACHINE IDLE			STARTING		
	ELEVATORS	MAKE TYPE FORM	H.P VOLTS AMP.	R.P.M.	WATTS AMPERES PHASE 1	PHASE 2	P.F H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F H.P.
108	Freight Elevator. Capacity 2 Ton. Load 175* Elevator going up.	Otis Elev.Co. Style QX	15.5 220	650 R	-680	2500	.497				3000	12900	.679
					21.5	22.	2.44				55	55	21.3
108	Same as Above Elevator going down				-1200	3500	.271				3130	13650	.786
					21.3	20.8	3.08				54.5	55	22.4
109	Freight Elevator. Capacity 2 Ton. Load 175* Elevator going up.	Otis Elev.Co. Style QX	15.5 220	650 R	4750	-260	.458				14000	25700	.89
					21.3	21.	6.01				56	58	39.8
109	Same as above. Elevator going down.				4000	-1030	.322				12500	4700	.786
					21.5	20.	3.97				51.	56.	23.
	CAKE AND CRACKER MACHINES.												
45	Motor Runs 5 Dough Mixing Machines Load - 2 Machines.	G.E.Co. KT C	7.5 220 18.5	1800 R 1840 E 1800 L	2200	1100	.885	990	0	.50	3300	370	.81
					10.3	10.3	4.55	6.4	6.4	1.33	45	45	4.91
51	Motor Runs 4 Mixing Machines Load - 1 Machine Mixing Heavy dough	G.E.Co KT C	7.5 220 18.5	1800 R 1790 L	1300	3900	.753				2200	7000	.772
					12.	12.	7.				50.	56.	12.3
55	"Green" Mixer, Direct Connected. Load - Mixing Soft Dough.	G.E.Co KT C	5 220 13.5	900 R	1010	2800	.77				1420	8600	.627
					13.7	13.2	5.1				60	57.5	13.4
56	"Green" Mixer Direct Connected Load - Mixing Cracker Dough	G.E.Co KT K	10 220 28	900 R 920 E 924 L	200	2600	.558	-960	1680	.155	2700	9300	.724
					15.1	14.6	5.58	12.2	13.7	.97	88	89	16.1
58	Spindle Mixer. Load - Spindles rising out of Cracker Dough. Readings Unsteady	G.E.Co I K	15 220 38	1200 R 1222 E 1179 L	6300	4200	.95	2000	-560	.306	15300	5400	.769
					36	35.4	15.6	12.3	12.6	1.92	125	127	27.6
50	Cake and Cracker Cutting Machine. Load - Making Fig Newtons.	G.E.Co I K	7.5 220 21.5	900 R	400	2150	.643	-470	1500	.289	1000	3430	.79
					11.2	11.6	3.42	9.8	10.2	1.38	27	26.2	5.95
49	Cake Cutting Machine Load - Cutting Soft Dough	G.E.Co. KT C	2 220 5.7	1200 R	-20	570	.474	-50	570	.435	700	3200	.669
					3.17	3.2	.74	3.07	3.27	.7	27	28	5.
48	Cake and Cracker Cutter Idle - On Idler.	G.E.Co. KT C	5 220 13.5	900 R 920 E 874 L	510	1540	.692	-100	1080	.432	2950	11000	.707
					7.	7.5	2.75	5.8	5.9	1.32	63.	63.	18.5
52	Bake Oven. Motor on Idler. Load 6 Seconds per Minute.	G.E.Co KT C	3 220 9.3	900 R 920 E 920 L	3300	1700	.874	660	-240	.26			
					14.1	14.6	6.71	5.5	5.5	.56			
59	Bake Oven Loaded 3 out of 25 Seconds Motor On Idler.	G.E.Co KT C	3 220 9.3	900 R 915 E	1300	2200	.909	-120	380	.352			
					10.3	11.3	3.36	5.5	5.5	.34			

		MOTOR RATING			MACHINE LOADED			MACHINE IDLE			STARTING		
	CAKE AND CRACKER MACHINES	MAKE TYPE FORM	H.P. VOLTS AMP.	R.P.M	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.
42	Belt Conveyer for Crackers.	G.E.Co. KT C	2 220 6.6	900 R				1010	-280	.31	6230	1100	.817
				880 E				5.2	4.75	.94	24	24.3	9.25
44	Cracker Conveyer.	G.E.Co. KT C	2 220 5.7	1200 R 1224 E	500	-90	.274				3250	800	.69
				1215 L	3.12	3.2	.55				25.	25.	5.41
46	Canvas Belt Conveyer Cake Frosting Machine Load - Maximum	G.E.Co. KT C	5 220 13.5	900 R	1040	-100	.429				7200	1470	.658
					6.	6.	1.26				56.	56.	11.6
53	Cracker Conveyer Load on this Machine would Require very little additional P.	G.E.Co. KT C	5 220 13.2	1200 R				990	00	.50	7450	1470	.652
				1224 E				6.8	6.	1.33	51.	51.	13.3
	AIR COMPRESSORS & BLOWERS												
33	Air Compressor Cylinder 8"x8"	G.E.Co. I K	30 220 75	900 R	2500	7500	.756	0	5000	.50	-4300	48400	.435
				916 E	41.	41.	13.4	24	27	6.7	400	395	59.1
34	Air Compressor. Load Pulsating. Starting Volts 145.	Crocker- Wheeler	50 220 121	900 R	11000	13750	.982	11000	13500	.984	62000	-11000	.374
				910 L	74	51	33.1	60	60	32.8	512	512	68.4
68	Air Compresser Cylinder 4"x8" No Starter	G.E.Co. MA. C	5 220 13	1800 R	-50	900	.451	-230	750	.219	3560	11360	.741
					5.5	5.5	1.14	5.	5.	.7	68	75	20
105	Air Compresser Pump 6"x6" No Starter	G.E.Co KT C	5 220 13	1800 R 1886 L	2050	3140	.94						
					15.6	15.6	6.95						
116	Air Compresser - Pump 6"x6" One Mech. Stoker and Emery wheel running idle during test	G.E.Co KT C	5 220 13	1800 R 1830 E	190	1760	.583	440	880	.192	3000	13500	.671
				1820 L	9.9	10.4	2.62	5.3	5.3	.59	70.	72.	22.1
72	Blower, 4' Diameter. Used for other loads, Mach. idle - Line Shaft 150'	G.E.Co I K	20 220 51	1200 R 1200 E	4830	300	.547	3900	-780	.358	33000	8000	.684
				1260 L	22.2	22.7	6.76	19.7	19.7	4.18	232	248	55.
91	Direct Connected to Centrifugal fan.	G.E.Co I K.	7.5 220 19.	1800 R	4430	3030	.96				11400	3750	.669
				1755 L	21.9	22.8	10.				98.5	98.5	15.4
104	Blower, 5.5' Diameter.	G.E.Co I L	50 220 125	900 R	5000	12000	.814				13100	21000	.925
				908 L	52.	57.	22.8				115	113	45.6
136	Fan 4' Diameter. Used to remove smoke from Room Direct Connected	Western Elec.Co CL9AB	3 440 3.75	450 R	170	810	.606				1000	1440	.954
					4.1	4.1	1.31				8.8	8.8	3.27

	BLOWERS	MOTOR RATING			MACHINE LOADED			MACHINE IDLE			STARTING		
		MAKE TYPE FORM	H.P. VOLTS AMP.	R.P.M.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.
142	Ventilating Fan 8'x4'11" 12 Point External Resistance Points 3,7,10,12 are for	Westing-house H.F.	15 440 20	870 R 551 (3d) 672 (7th)	1870	5000	.783	1100	4750	.669	1010	3950	.703
						Seventh Point			Third Point				
					14.1	14.1	9.2	11.2	11.2	7.84	13.1	10.9	6.73
	Running. Motor Direct Connected Used on 7th Point.			765 (10th) 846 (12th)	3400	8000	.819	2530	6750	.799			
						Twelfth Point			Tenth Point				
					21.	21	15.3	17.5	17.1	12.4			
	SPICE GRINDING MACHINES												
75	Run 33 Grinders and Shakers	G.E.Co. I K	50 220 124	900 R 912 L	10000	2000	.654	9000	1500	.627	78000	16150	.66
					51.	54.	16.1	42	44	141	550	550	126.
76	Run 24" Powdering mill	G.E.Co I K	35 220 82	1800 R	9500	13500	.957				11400	50200	.676
					60	60	30.9				300.	290.	82.5
78	Runs 24" Powdering mill Similar To #76	G.E.Co. I K	35 220 82	1800 R 1773 L	12300	4500	.779						
					49.5	48.5	22.6						
83	Runs 24" Pulverizer	G.E.Co I C	10 220 24	1800 R 1835 A 1805 E				190	1660	.592	2330	15900	.613
								8.8	8.3	2.5	103.	103	24.4
85	Runs 22" Pulverizer	Western Elec.Co CS11A	15 220 37.5	1800 R 1806 E	3350	1490	.834	2600	920	.772	12500	3000	.684
					14.6	14.6	7.81	12.3	11.8	4.72	104.	105.	20.8
86	Runs 2-22" Pulverizers.	G.E.Co I K	15 220 38.	1200 R 1225 A 1214 E				1010	4350	.678	10900	30000	.779
								20.5	19.	7.18	207.	207	54.8
89	Run Pulverizer.	G.E.Co. KT C	15 220 35.5	1800 R 1815 L	3530	1290	.77	3160	735	.68	19000	8000	.817
					15.2	16.7	5.78	14.8	15.2	5.21	130	140	36.2
110	Grinder.	G.E.Co I K	15 220 38.	1200 R 1240 L	1490	4180	.721	1110	4080	.662	400	23500	.57
					21.5	21.	7.2	19.5	19.5	9.9	163	155	31.9
	MACHINE SHOP.												
22	Drill Press and Lathe.	G.E.Co. I. K.	3 220 7.85	1800 R 1840 L 1825 A	70	650	.583	-50	600	.433	1800	5600	.747
					3.8	3.5	.97	4	4	.74	41.	41.	9.93
23	Drill Press. Direct Belt Drive. No Starter.	Westing-house CCL	.5 220 1.8	1700 R 1800 A 1787 L	360	111	.738	230	-21	.432			
					1.7	1.7	.63	1.	.9	.28	8.5	8.5	
24	Trip Hammer, Shears, 12" Emery wheel, hack saw, bolt threader No Starter.	G.E.Co I K	3 220 7.6	1800 R 1804 A 1818 E	1300	500	.792	630	-50	.441	6650	1400	.612
					5.9	5.4	2.42	2.5	1.9	.78	41.	41.	10.8

	MACHINE SHOP	MOTOR RATING.			MACHINE LOADED			MACHINE IDLE			STARTING		
		MAKE TYPE FORM	H.P. VOLTS AMP.	R.P.M.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.
37	Drill Press; Punch-max 1"x4.5" hole; Flange Punch; Shear; Roller; Blower.	G.E.Co. I K	15 220 38	1200 R	5400	4450	.98	2800	200	.554	3000	1000	.756
				1225 A	28.7	30.	13.2	14.5	15.	4.02	133.	132.	5.36
73	Lathes; Milling machine, Emery wheels; etc. No starter.	G.E.Co. KT C	5. 220 13	1800 R 1797 A	540	1480	.779	0	915	.50	3670	16200	.675
				1768 L	7.5	7.5	2.71	5.5	6.	1.23	74	77	26.6
101	Ten Drill-presses, emery wheel, Crimper, Blower.	G.E.Co. I K	25 220 63.	1200 R	1540	4000	.804	390	3260	.594	7800	25800	.729
				1223 E	21.5	21.5	7.31	7.5	7.5	4.89	323.	324.	45.
103	Drill-presses; Shears; Iron cutter; Emery Wheels. No Starter.	G.E.Co KT C	5 220 13	1800 R	470	1380	.761				4200	9500	.83
				1816 L	6.2	6.4	2.34				86.	87.	18.4
	GRIND STONES												
122	Surface Grinder, Grind on flat side of Stone; Stone 3.5" to 12." x 28 Diam. Test 8"x 28" Load Intermittent	Westinghouse CCL	7.5 440 10.2	1120 R	4670	13490	.764	40	1640	.52	600	12280	.553
				1170 E	30.	32.	24.3	5.	5.	2.25	39	37	17.3
123	Automatic Surface Grinder; Grind on Flat side. Stone 3.5" to 12" x 48". Steady Load	Fairbanks Morse Co B.V.	30 440 38	1200 R	14080	8100	.904	5600	-800	.389	12000	10400	.99
				1148 L	40.4	45.4	29.7	18.5	18.2	6.43	55.	55	30.
124	Grind Stone. Load on only a few seconds.	Westinghouse H.F.	15 440 20	870 R	9800	8400	.996	5300	2800	.881	6430	4880	.972
				868 E	23.7	23.7	24.2	8.3	8.4	10.9	19.8	19.8	15.2
125	Grind Stone. Size 13"x8' Load Intermittent.	Fairbanks Morse Co. B.V.	30 440 38	720 R	16570	8650	.877	4570	1200	.698	12440	9800	.982
				730 E	40.3	42.3	23.8	15.3	15.3	7.74	38.	39.	29.8
126	Grind Stone. Size 13" x 6' Diam.	Westinghouse. H.F.	20 440 28.7	690 R	7600	4150	.89	3800	-2200	.15	11290	5380	.851
				718 L	17.2	12.3	15.7	11.1	17.5	2.14	24.	24.	22.3
127	Stone 6"x 28". Grind on Surface.	Westinghouse CCL	7.5 440 10.1	1120 R	6350	2770	.822	2000	-96	.469	6400	270	.532
					14.8	15.8	12.2	5.	5.	2.55	40	43	8.94
128	Grind Stone Grinding Reaper Blades.	Westinghouse. CCL	10 440 12.8	850 R	10250	4660	.836	1500	-200	.391	7700	600	.559
				868 E	30.	30.	20.	2.7	2.7	1.74	35.	50.	11.1
130	Grind Stone; 13"x46" Diam. Loaded about 80% of time.	Westinghouse. H.F.	15 440 20	870 R	4930	9400	.879	1100	3800	.723	2800	4600	.921
				848 L	24.	26.1	19.2	9.9	9.1	6.56	13.3	13.5	9.9
131	Grind Stone; Size 12"x 18".	Westinghouse. H.F.	15 440 20	870 R	7850	5750	.965	1800	-160	.473	5374	3160	.913
				824 L	22.1	22.1	18.2	6.9	7.4	2.2	13.5	13.5	11.4
132	Grind Stone. Size 8"x30' Test - Grinding Surface of die.	Westinghouse CCL	20 440 26	850 R	8200	9000	.996	2000	2400	.986	4900	7300	.946
				905 E	25.3	25.8	23.	9.8	7.4	5.9	73.	71.5	16.3

	GRIND STONES	MOTOR RATING MAKE. TYPE FORM	H.P. VOLTS AMP.	R.P.M.	MACHINE LOADED WATTS AMPERES PHASE 1	PHASE 2	PF H.P.	MACHINE IDLE WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.	STARTING. WATTS AMPERES PHASE 1	PHASE 2	P.F. H.P.
133	Grind Stone; Size 4"x18" No starter	Westing- house. CCL	2 440 2.83	1120 R	190	650	.689	140	620	676	460	4000	.601
					1.5	2.	1.13	1.5	2.	1.02	15.1	14.8	5.98
134	Grind Stone.	Westing- house H.F.	15 440 21.	690 R	5600	4300	.975	4800	2000	.814	7000	6330	.997
				710 L	13.4	14.2	13.3	8.3	8.6	9.11	23.3	24.3	17.9
	MISCELLANEOUS												
20	Bottle Washing Machine; Mach. empty at Test. Machine is the heaviest part of load.	G.E.Co. KT C	5 220 13.2	1200 R	1040	-300	.303				2000	1300	.938
				1230 L	6.5	7.	1.				60.	62.	4.42
21	Barrel Washing Machine.	G.E.Co I C	5 220 13.	600 R	1650	-845	.187	1450	-960	.116	8600	800	.569
					12.2	12.7	1.08	12.4	12.4	.66	62.5	63.	12.6
29	Loeb Monitor Beer Pasteurizer Heated by Steam. Machine makes one Rev. per. hour.	G.E.Co I K	10 220 29	900 R 930 A 900 L	2290	-20	.494				6500	1200	.647
					13.8	14.2	3.04				80	61	10.3
57	Buffer: Direct Connected Loaded 20 sec. per. minute.	G.E.Co KT C	5. 220 13.5	3600 R	2250	3250	.954	-215	1050	.358	2700	16100	.629
				3512 L	14.1	15.1	7.38	6.8	7.3	1.12	100.	86.	25.6
70	Runs 9 Machines for making tin cans; 160' of 2" line Shaft.	G.E.Co. I K	15. 220 32.	1200 R	4150	470	.586	3350	-910	.313	38500	6600	.636
				1212 L	24.3	24.2	6.2	23.3	23.3	3.13	170	178	60.5
72	Runs 30 Presses To stamp out parts for Tin Cans. All machines belted direct to line shaft.	G.E.Co I K	20 220 51	1200 R	6850	4450	.938	3200	-780	.358	33000	8000	.684
				1179 L	38.	38.	14.2	Line Shaft Only 19.7	19.7	3.92	232.	248	59.
100	Planer; Shaper and 6 Circular Saws. Tests with Mach. loaded and with Line shaft.	G.E.Co I K	50 220 124	900 R 920 E 915 L	0	9300	.50	-3000	6500	.208	8100	65000	.532
					77.	82.5	12.5	41.	41.	4.7	525	532	98.
106	Run sand cutting machine. For use in foundry.	G.E.Co KT C	7.5 220 18.5	1800 R	2050	890	.825	875	-145	.383	9800	11900	.665
					7.4	6.5	3.86	4.5	4.	.98	70.	72.	16.

TABLE OF TRADE NAMES OF MOTORS.

NAME OF MAKER.	SQUIRREL CAGE	INTERNAL RESIS.	EXTERNAL RESIS.	REPULSION.
G.E. Co.	Type I Form K	Type I Form L	Type I Form M	Single Phase RI.
G.E.Co.	Type I Form C	Type I Form LM		
G.E.Co.	Type KT Form C			
Westinghouse Elec.&Mfg. Co	Type MS		Type HF	Single Phase Type AR
Westinghouse Elec.&Mfg. Co	Type CCL		Type MW	
Westinghouse Elec. & Mfg. Co.			Type F #100	
Fairbanks Morse Co.	Type B		Type BV.	
Western Electric Co.	CL9AB			
Otis Elevator Co.			Style 10 AC	
Otis Elevator Co.			Style QX	
Northern Electric Co.			Type O Form X	
Crocker Wheeler Co.	Size 350			
Wagner Electric Co.	Type BP. Model 19T			

IV

TABLES OF TEST DATA AND DISCUSSIONS WITH INDIVIDUAL CONCLUSIONS.

In the discussions of the following groups of machines one object is to show the proper size of motor to use in order to obtain high efficiency for the running conditions. A few examples are given of the saving that may be expected by the proposed changes. The other object is to provide for the starting of the load without excessive flow of current or power.

The following is a key to the speed notation of the tabulations of data:- A = motor alone; E = machine empty; L = machine loaded; R = rated speed.

a. PUMPS.

For all the tests of this group the starting current is from four to ten times the rating of the motor. The power input is 150% to 300% of the motor rating. In all cases a smaller motor could be used for running and for the small size of these motors the comparatively large starting currents would not be objectionable to the central station. For large pumping sets rotor resistance motors should be used but where automatic float starters are used, it is almost necessary to use a squirrel cage motor.

In this group Motor No. 26 is the only one of the right size for the work done. It ran at nearly full load, had good power factor and speed regulation. Motors Nos.27 and 28

should each be replaced by a 1 H.P. motor.

b. ELEVATORS.

It is different to make recommendations for this group since at no time was it possible to get full load on the elevator. Except for the first two, all motors have an external rotor resistance, but in starting this resistance is generally cut out before the motor has much more than started. The data for No. 19 is interesting because the power is negative for the motor going up. This indicated that the counterweights are extra heavy for the light load on the motor.

Motor No. 19 should be replaced by a 1 H.P. motor and a countershaft provided to allow the motor to come up to speed before throwing on the load. Motor No. 35 could be replaced by at least a 20 H.P. and if a friction clutch were provided it could probably start the elevator and conveyer when full of coal. At present both the elevator and conveyer must be empty or the motor will not start.

c. CAKE AND CRACKER MACHINERY.

The size of motor required for the mixing machines cannot always be decided from the data taken since the consistency of the dough varies. No. 56 and No. 58 are always used for the same purpose and the data there is reliable. No. 56 should be replaced by a 5 H.P. motor. While this would result in a saving of power it would not be very great since the motor is used only a few hours per day.

The maximum load is given for No. 58 and that load is applied for only a few seconds. The normal power input is 11 H.P. Therefore it would pay to use a 10 H.P. motor which would easily carry the overload for the few seconds required. For starting, the spindles are revolving free and a high starting torque is not required. Hence the starting voltage of 125 volts could be reduced, cutting down the starting current. A rotor resistance motor is not recommended for this machine because its efficiency is less than for the squirrel cage type, and the starting conditions do not demand it.

Motor No. 45 is installed large anough to run three small mixers and two larger ones. The three small ones are seldom used. The data is taken for the two large mixers and the line shaft. A more economical arrangement would be to use the three small mixers in one group with a motor of proper size, and to use the other two in another group. Then by reducing the length of the line shaft a 3 H.P. could be used.

The power taken by the cake and cracker conveyers loaded isonly a little more than that taken to run them empty. Motor No. 46 should be replaced by a 1 H.P., No. 44 by a 1/2 H.P. and No. 42 by a 1 H.P. No. 53 could be replaced by a smaller motor but a test should be made with the conveyer loaded before deciding definitely.

The cake and cracker cutting machines include endless belt conveyers to carry the pans under the cutter, and sometimes a device for rolling out the dough. Consequently the power required to cut the crackers or cakes is negligible. As is seen from the data for Motors No.48, 49, and 50, a smaller size of motor should be used in each case.

The two momentary loads on Motors No.52 and No. 59 could be lightened by using a fly wheel on the idler with the motor. While the present conditions are not serious for these small motors they would become so with large installations.

d. AIR COMPRESSERS.

In this group Motor No. 105 is of the proper size while all the others are too large for the work done. In all of the squirrel cage motors the starting current and power is excessive as compared with that to carry the load. Motor No. 33 could well be changed to a 10 or 15 H.P. rotor resistance motor, with a consequent saving of from 2 1/2 to 3 H.P. in losses.

Motor No. 68 was installed as a 5 H.P. in order to carry a small additional load which is used only a few times per year. The air compresser is used continuously. A considerable saving of power could be made by using a 1 H.P. motor starting on a counter shaft for the air compresser, and a similar one for the other additional load.

Motor No. 104 is of the proper type but should be a 20 H.P. This motor is used ten hours per day about 300 days

per year. The efficiency of the 50 H.P. motor is about 85% at 22 H.P. input and the loss is 3.3.H.P. If a 20 H.P. motor is used the efficiency is 88% and the power lost if 2.64 H.P. The net saving is 2/3 H.P. which at $.05 per Kw.Hour is $74.00 per year.

Motor No. 91 is an example of a motor run at about 1 H.P. overload, apparently with no bad effects. However, the efficiency is about 1% lower than at from 60% to 100% load.

The results for No. 142 are interesting. The fan is direct connected to an eight pole motor of 900 R.P.M. at synchronous speed, so that the speed reduction to 670 R.P.M desired could not be obtained by use of belt and pulleys. The company chose to use a rotor resistance motor and run continuously for ten hours per day at 75% synchronous speed. The efficiency at that speed is about 66% while if a ten pole motor at 720 R.P.M. synchronous speed were used the efficiency would be increased to about 87%. For the first case the loss is 4.1 H.P. For the second case with a 10 H.P. motor the loss is .91 H.P. and the saving is 3.19 H.P. At $.05 per Kw. Hour, ten hours per day and 300 days per year, this would amount to $478.50 . Since the fan is used for during noon hour part of the time it is probable that over $500 per year could be saved.

In concluding the discussion of this group it is recommended that the large size motors be replaced by smaller ones and that they have rotor resistance for starting purposes. In general large fans require a high starting torque thus

making the use of the rotor resistance type of motor advisable.

e. SPICE GRINDING MACHINERY.

All the motors of this group are much too large. In fact as a result of these tests the company has made many changes in the sizes of the motors used. In the test No. 75 it was found that a large percentage of the power was used in the line shafting and belts. It would be advantageous to put the machines seldom used in one group with a motor of proper size to run them, and to have a similar group for the other machines. From the data given it is plain that smaller motors should be used and that they should be squirrel cage type with friction clutches or that rotor resistances should be used.

f. MACHINE SHOPS.

In most machine shops it would be possible to use a friction clutch with the line shaft. Then even if the shaft is long and has a number of machines belted to it the more economical squirrel cage motor can be used. In general the long shafts with a number of pulley and belts require a high

starting torque.

The data taken for Motor No. 24 under "Machine Loaded" was taken for the maximum indication of the instrument needle when the trip hammer was used. A heavy fly wheel could be put on the trip hammer countershaft and the 3 H.P. motor replaced by a 1 H.P.

A very large saving may be made by replacing Motor No. 101 with a 7.5 H.P. motor. The present efficiency is 76% and the loss is 1.75 H.P. Using a 7.5 H.P. motor and the same output of 56 H.P. the percent load is 74.5 %, and the efficiency is 88%. For these conditions the loss is .75 H.P. or a net saving of 1 H.P. At $.05 per Kw.Hour, ten hours per day and 300 days per year, the saving is $111.90.

g. GRINDSTONES.

As all large grindstones have large inertia and require a high starting torque a rotor resistance type of motor should be used. In many of these tests the data given ~~is~~ for "Machine Loaded", is the maximum power input and occurs for only a few seconds, since the load is applied for a few seconds. Some of the grindstones are of small size and this maximum power input is excessive, indicating that the inertia is low. Under these conditions the central station man would want inertia to be provided artifically as by the addition of a heavy fly wheel. The customer should be willing to provide the fly wheel because the heavy currents otherwise resulting cause extra heating and strain on the motor.

The test for Motor No. 122 shows that with the

squirrel cage motor heavy starting current and power of about 350% and 200%, respectively is required. For ordinary running conditions 2.25 H.P. is required, and momentarily 24.3 H.P. input. A 5 H.P. motor with rotor resistance would cost less than a squirrel cage type with compensator , and better starting torque would be obtained. The addition of a heavy fly wheel would very largely reduce the momentary heavy rush of current. Motor No. 123 is well adapted for its work. For both starting and running the current and power are very satisfactory. Motor No. 128 should be replaced by a 5 H.P. motor or perhaps a still smaller one, and a fly wheel should be added to give up its energy during the few seconds that the load is applied. The present starting power is comparatively low for a squirrel cage motor with a compensator, showing that the inertia of the rotating parts is low.

h. MISCELLANEOUS.

Motor No. 72 is noticeable for its inadaptability to start the heavy load. The machines all have heavy fly wheels and are all belted directly to the line shaft. When the motor is started a number of men have to help by pulling on the belt. It required thirty seconds to a minute for the motor to reach any speed. After the motor was running it was found that the power taken for the machines working or idle was very nearly the same, due to the heavy fly wheels. A 15 H.P. rotor resistance motor should start the load and carry is satisfactorily. It would probably be a little more economical to use a

squirrel cage motor and a friction clutch in the line shaft. Motor No. 70 has about the same conditions of operation as No. 72 and the same changes could be made.

Motor No. 100 is another example of a poor choice of motor. To cut down the losses the line shaft is run in ball bearings but any gain this way is offset by the low efficiency of the motor installed. A 15 H.P. rotor resistance motor would start and carry the maximum load.

Motor No. 51 is of interest since it is the only two pole motor tested. The buffer is direct connected to the motor shaft and not much additional power is required to run it idle. Then for "Machine Idle" the power input is nearly all to run the motor. That power is about 20% compared with the usual power of about 10%.

V

GENERAL CONCLUSIONS.

As a result of this investigation it was found that in almost every case the motor was larger than required for the work to be done. In some cases this was due to ignorance of the actual needs and in other cases due to the wrong idea that for the same load it would cost no more to run the large motor than the small one. Again in a few cases where a high starting torque was required, large squirrel cage motors were installed when a small motor and friction clutch should have been used. In other cases a smaller rotor resistance motor should have been used. Very few of the consumers realize that there is any relation between efficiency and percent load on the motor. None seemedto understand that for the same efficiency the large motor has larger losses.

If the changes suggested are made it will result in higher economy of operation and a saving to both the consumers and the central station, and the company will obtain the good will and confidence of the consumers to an extent that could not be obtained by any other means.