OPTIMUM VALUES OF THE CAPACITANCES IN SINGLE PHASE CONDENSER MOTOR

By

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In this work, the writer is deeply concious of his great debt to various writers and in its course, many technical Journals and especially the Transactions of the American Institute of Electrical Engineers and Electrotechnik und Maschinenbau, have been consulted and in addition, use has been made of the work of M. Krondl.

Due acknowledgement has been made in the Bibliography at the end of this cover, of the sources from which the information has been drawn..

May, 1961. K.R.S. Jain

PREFACE

In presenting this dissertation on the capacitor motor, the writer is aware of the fact that he is entering a field in which there are already many excellent works. However, an attempt is made to present the subject from a somewhat new standpoint. The writer's aim has been to present so much of the theory as is necessary to understand the phenomena of these motors, so far as these phenomena relate to the performance of single phase Induction Motors.

For the most part this dissertation is the calculation of the optimum values of the capacitances in a single phase Capacitor Motor and developes the various relationships. A direct method of calculation is employed, based on the theory of Symmetrical Components for two phase unbalanced motors. This method gives accurate results independent of empirical or restricted premises. The object of this work is to give a mathematical theory of the same and to present the results of calculations in a given motor of $\frac{1}{16}$ h.p., 220 volt, 50 c/s, 4-pole, 1-ph., Capacitor type.

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TABLES:

INSERTION:

LIST OF SYMBOLS & SUFFIXES

SYMBOLS		SUFFIXES	
I	Current(Amps.),	U	Main phase or winding
U	Voltage, Supply volts (Volts),	V	Auxiliary phase or windi
C	Condenser capacity (μF),	C	Pertaining to condenser,
R	Resistance (Ω),	1	Positive phase-sequence,
X	Reactance (Ω),	2	Negative phase-sequence,
Z	Impedance (Ω),	S	Syn.speed working, Stator
Y	Admittance ($\mho$),	s	Standstill,
K	Distribution fac-tor,	r	Rotor,
f	Line frequency (C/Sec.)	i	In-put,
S	Slip,	o	Out-put,
N	Speed (r.p.m.)	Fe	Iron,
n	No. of phases,	R	Friction & Windage,
B	Flux density (Gauss),	h	Magnetising,
Φ	Flux (Maxwells),	res	Real,
φ	Power factor angle,	rec	Imaginary,
ϑ	Torque angle,	net	Total,
T	Torque (Syn.Watts or cmKgs.),	f	Forward,
V	Losses (Watts),	b	Backward,
p	No. of poles,	w	Winding,
P	Power (Watts),	'	Transfered to stator side
H	Power (h.p.),		
α, a	Turns & copper weight ratio of main to auxiliary winding		
η	Efficiency,		
p.f.	Power factor,		

a,b,c,A,B,D,F,K,Q,etc.-Complex variables.

1. INTRODUCTORY

The induction motor is now the most widely used of all machines and with the rapid increase which has recently been taken place in the number of motors applied to such semi-continuously operated domestic & small industrial loads as household refrigerators, fans, grinders & drillers, it would be extra-ordinarily important to call for careful examination of the typical characteristics of these motors. Such motors operating on single phase line of lighting, or power circuits, or any phase of a poly-phase system, and running all the hours, must have quiet running, low starting current to prevent flicker of lights, high efficiency & starting torque and should not give rise to radio interference.

As the Single phase induction motors have no inherent starting torque, they may be started by hand, by mechanical means, or by some special electrical means but are usually made selfstarting by some special method of winding. These motors have been named according to the methods of their self starting, such as split phase, reactor, repulsion, capacitor & shaded pole type. Each type has special desigms to make it more suitable for a specific application.

Now of all the types of single phase motors available, the capacitor motor seems best suited for services of relatively small outputs & especially in the fractional horsepower field. It is extensively used for fans, blowers, pumps, compressors, oil burners, washing and iron machines, grinders, drillers, water pumping, milking, bottle washing, milk cooling, hay baling, corn-husking, corn shelling, grain drying, threshing, etc.etc.

In a capacitor motor, self starting is achieved by means of a split phase winding, generally called the capacitor or auxiliary winding. This winding is displaced in space, 90 degrees electrically from the main winding, and both are connected in parallel directly to the single phase line. The performance of the motor can perhaps best be understood by considering it as a two phase induction motor with unbalanced conditions of winding and voltage and the characteristics may be deduced with the help of Symmetrical Components.

The predetermination of the performance and calculation of the optimum values of the capacitances, at various slips for a single phase capacitor motor presents an interesting problem from both practical as well as theoretical point of view. Since in case of 1-ϕ, C-Motors, the convential theory of the polyphase induction motors does not hold even at balanced conditions of winding & voltage and as such the problem calls for an examination of the various relationships through the theory of the Symmetrical Components.

In the following, an effort has been made to predetermine the performances and to calculate the optimum values of the capacitors from design data for a given motor.

2. THEORETICAL ASPECTS OF THE PRODUCTION OF TORQUE IN SINGLE PHASE MOTORS.

Chapter out line:

2.1. Two theories of single phase induction motor action for calculation of torque developed.

2.2. Starting methods.

a. Shaded pole.

b. Repulsion,

c. Split phase- Calculation of starting torque.

d. Capacitor - Calculation of starting torque.

2.3. Capacitors.

2.4. Symmetrical components theory as it is applied to split pha
two winding motors.

2.1. Two theories of single phase induction motor action for calculation of torque produced:

a. Cross field Theory.

When a single phase induction motor is connected to an alternating current source, the resultant field alternates along one axis only. Such an alternating field acting on a stationary rotor cannot produce any unidirectional starting torque, but onc
the rotor starts revolving, however, it accelerates and continue
to revolve in the direction of rotation as long as load is not excessive. According to the theory when the rotor starts revolvi
it produces a cross flux that is in both space and time quadrat
with the main axis flux and, therefore, the two conditions necessary to produce a rotating field are fulfilled.

The above concepts are taken in what is known as cross field Theory.

b. Double Revolving field theory.

A different approach for the single phase motor action can be explained by the double revolving field theory. The idea is taken from the Euler's expression for the cosine of an angle. If an alternating voltage E_m Cost wt is impressed on a single phase winding displaced in space with respect to some reference, such that angular displacement corresponds to distance 'X', the resultant field can be represented as

$$E_m \cos wt \sin x = \tfrac{1}{2}E_m \sin (x + wt) + \tfrac{1}{2}E_m \sin (x - wt)$$

Here the right hand side of the expression represents two rotating fields in opposite directions, & of half magnitude but with the same angular velocity w.

Thus when the rotor once start rotating in either direction, the torque produced by the forward flux is greater than that of the backward flux and the resultant torque accelerates

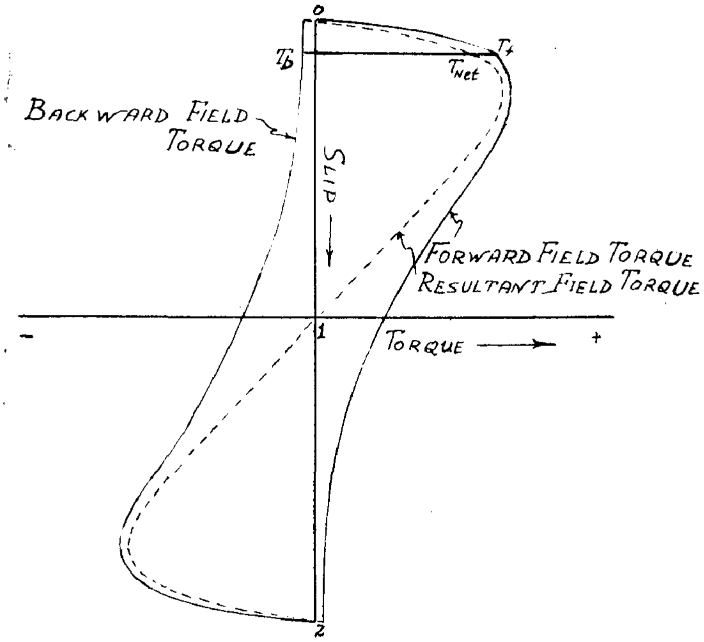


Fig. 2.1.1 — Torque produced by each Component of the Double-revolving field Theory.

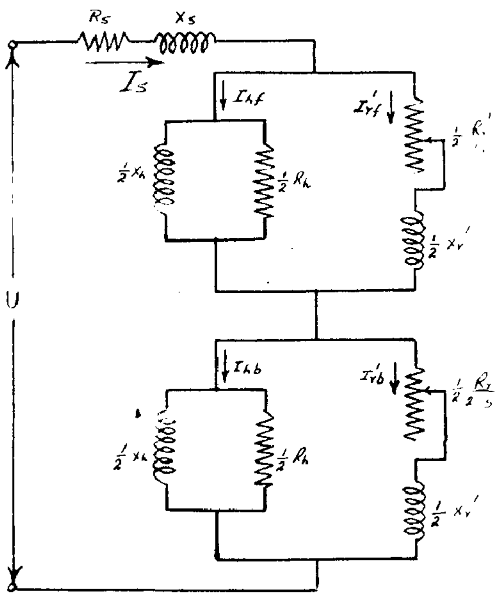


Fig. 2.1.2 — Equivelent Circuit for th 1-φ motor based on 2-field theory.

the rotor till it reaches a fixed revolutions per second and so, in running condition, the action is nearly that of a poly phase motor.

The equivalent circuit diagrams for single phase induction motor based on this theory is shown in fig. 2.1.2.

As the forward field operates at a slip S, the corresponding slip for the backward rotating field is (2 - S).

The forward torque is given by

$$T_f = I'^2_{rf} \frac{Rr'}{2S} \text{ in Syn. watts,}$$

and the backward torque is $T_b = I'^2_{rb} \frac{Rr'}{2(2-S)}$ in Syn. watts. Hence, the resultant torque is the difference of the two at a particular slip,

$$T_{net} = T_f - T_b$$

2.2. Starting Methods:

Because the single phase induction motor with only one stator winding has no inherent starting torque, various methods have been developed for starting. Only four of these methods are at present of commercial importance.

a. Shaded Pole Motor. The shaded coil method of starting is employed in some fractional horse power motors. The stator winding of such a machine is not distributed around the frame, but is wound in the form of coils placed around projecting pole pieces. One side of the shading coil is placed in a slot cut in the pole piece. The effect of the shading coil is to make the flux 'b' delayed with respect

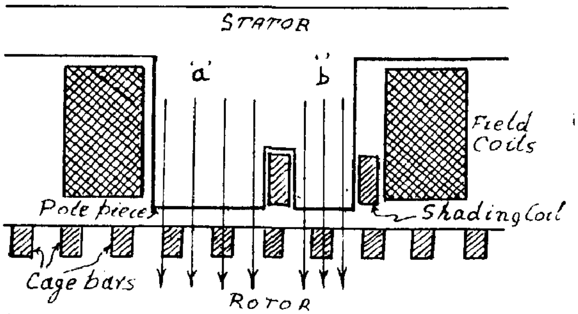


Fig. 2.2.1 — Shaded Pole Motor.

to the main flux 'a' of the pole. The combined action gives a sweeping action, magnetically, across the pole face, resulting in a revolving flux and consequently providing the starting torque.

b. Repulsion Motor: Several types of single phase motor use the repulsion principle of starting, & can be classified under the following heads:

(i) Repulsion start induction Motor:- The armature or rotor of the motor is similar to that of the d.c. machine, except that the brushes are short circuited, & also a mechanism short circuiting the armature winding through the commutator bars at about 70% of the synchronous speed by a centrifugal device is done and the motor then operates as a single phase induction motor.

(ii) Repulsion Motor: It starts as a repulsion motor, also runs as such, and is a varying speed motor with speed- torque characteristic similar to the direct current series motor.

(iii) Repulsion induction Motor:- This motor has the repulsion winding for starting and in addition it also has a squirrel cage winding. As soon as the repulsion winding starts the motor, the squirrel cage winding also produces torque. Both the windings are active all the time while the motor is in operation.

Brush positions in a Repulsion Motor:- The armature of the repulsion motor is similar to that of a d.c. machine. The brushes are shifted through a considerable angle from the positions normally occupied on the d.c. armature and short circuited. Speed Reversal

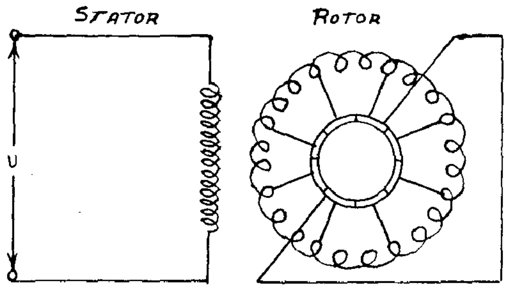


Fig. 2.2.2 — Repulsion Motor

of this type of motor is accomplished by a shifting of the brushes to the opposite side of the neutral plane of commutation

<u>c. Split-phase Motor</u>:- The split phase motor is made self starting by means of an auxiliary winding. This winding is displaced 90 electrical degrees from the main winding. This auxiliary winding through a resistor R_o or a reactor X_o is connected directly to the single phase supply lines, in parallel with the main winding.

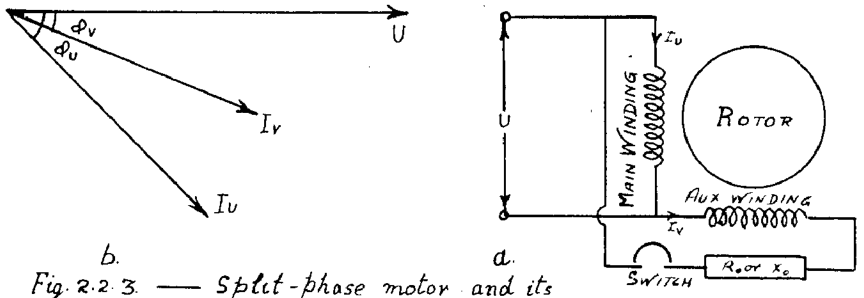


Fig. 2.2.3. — Split-phase motor and its Vector diagram.

Such motors are designed so that the currents vectors Iu & Iv are about 25° to 35° out of phase in time. Considering that these two vectors represent the respective stator winding currents of a split phase induction motor, it can be seen that the single phase supply results in current and fluxes displaced in space and time, and so yields a starting torque. Combined operation on both windings results in rapid over heating and inefficient, noisy performance and, therefore, a centrifugal switch on the rotor disconnects the auxiliary or starting winding at about 2/3rd of Syn. speed.

Both the split phase and capacitor start motors have the starting winding coils wound with a size of wire that is gernally smaller than that used in the main winding. The size of wire and the number of turns per coil are so as to give the proper starting torque for the machine the motor is to operate.

To perform the function of opening the starting or auxiliary winding at about 2/3rd of syn. speed, some times, in a few cases a special magnet operated switch is used in place of one operated by centrifugal force. When the motor is started, the current is higher than the full load current and the magnet coil is designed to close the switch on this high value of current. As the motor picks up the speed the current decreases and finally comes to full load value. Now as the current reaches a value that will no longer allow the magnet to hold in the switch, it drops out and opens the starting winding. The value of the current at which the switch drops out is so chosen as to open the auxiliary winding circuit at about 70% of the syn. speed.

Calculation of starting torque in resistance split phase moto

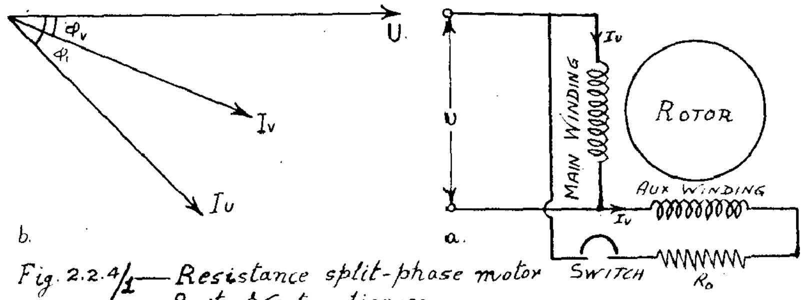


Fig. 2.2.4/1 — Resistance split-phase motor & its Vector diagram

If the fluxes due to the two windings differ 90 electrical degrees in space phase and have sinusoidal variation in both time and space, the torque will be proportional to their product and to the component of one at right angles to the others.

Therefore, $T_s \propto B_u B_v \sin\vartheta$

$$\text{or } T_s = Q B_u B_v \sin\vartheta \quad \text{—— } 1$$

where Q is a constant of proportionality

Here, $\sin\vartheta = \sin(\varphi_u - \varphi_v)$

$$= - \text{Cos } \phi_u \ \text{Sin } \phi_v + \text{Sin } \phi_u \ \text{Cos } \phi_v$$

$$\text{or} \quad \text{Sin } \vartheta = \frac{X_u(R_o + R_v) - R_u X_v}{Z_u Z_{ov}}$$

$$\text{So,} \quad T_s = Q B_u B_v \frac{X_u (R_o + R_v) - R_u X_v}{Z_u \ Z_{ov}} \quad - 2$$

Now, if we neglect saturation, B_u & B_v are proportional to their ampere turns, So,

$$B_u B_v \propto N_u N_v I_u I_v$$

$$\text{or } B_u B_v = F N_u N_v I_u I_v \quad \text{——} 3$$

When F is a constant of proportionality, and substituting it in equ^n. 2, we have

$$T_s = QF N_u N_v I_u I_v \frac{X_u (R_o + R_v) - R_u X_v}{Z_u Z_{ov}}$$

$$\text{Also} \quad I_u I_v = \frac{U^2}{Z_u Z_{ov}}$$

Therefore, torque equ^n. becomes

$$T_s = QF N_u N_v U^2 \frac{X_u (R_o + R_v) - R_u X_v}{Z_u^2 Z_{ov}^2}$$

$$= \frac{QF N_u^2 U^2}{Z_u^2} \quad \frac{X_u (R_o + R_v) - R_u X_v}{\alpha Z_{ov}^2} \quad -4$$

Further, torque for a balanced two phase motor is

$$T_{st} = \frac{QFN_u^2 U^2}{Z_u^2} \quad - 5$$

$$\text{So,} \quad T_s = T_{st} \frac{X_u (R_o + R_v) - R_u X_v}{\alpha Z_{ov}^2} \quad -6$$

The condition for maximum starting torque is found by assuming the external resistance Ro as variable.

$$\frac{d T_s}{d R_o} = 0 = \frac{X_u(\overline{R_o + R_v}^2 + X_v^2) - [X_u(R_o + R_v) - R_u X_v] 2 (R_o + R_v)}{\alpha [\overline{R_o + R_v}^2 + X_v^2]}$$

$$\text{or} - X_u (R_o + R_v)^2 + X_u X_v 2 + 2 R_u X_v (R_o + R_v) = 0$$

or $(R_o + R_v)^2 \; X_u \; - 2 \; X_v (R_o + R_v) - X_u X_v^2 = 0$

or $R_o + R_v = \frac{X_v}{X_u} \left[R_u \pm \sqrt{R_u^2 + X_u^2} \right]$

or $R_o + R_v = \frac{X_v}{X_u} \left[R_u \pm Z_u \right]$ here -ive sign is absurd as -ive resistance has no meaning.

Therefore, $R_o + R_v = \frac{X_v}{X_u} (R_u + Z_u)$ ...7

Substituting this value in the expression of standstill torque, we have, $T_{sm} = T_{st} \frac{X_v^2}{X_u^2} \frac{1}{2\alpha (Z_u + R_u)}$ ---8

Now if the constants of the main winding are taken unaltered then, $T_{sm} \propto \frac{X_v^2}{\alpha}$

or $T_{sm} \propto X_v^2 N_v$ & also as $X_v \propto (R_o + R_v)$ for max^m torque.

That is T_{sm} can further be increased to any value desired by either increasing the auxiliary winding turns to a suitable value or by increasing the external resistance R_o such that $(R_o + R_v)$ is proportional to X_v by changing the wt. of copper in the auxiliary winding.

d. Capacitor motor.

There are numerous types of capacitor motors available and the difference being found in the capacitor unit and the method used to connect it into the circuit. These motors can be classified under the following heads:-

(i) Capacitor start motor:- This motor is similar to split phase motor, except that a condenser is used instead of a resister or a reactor in series with auxiliary winding for the starting period only.

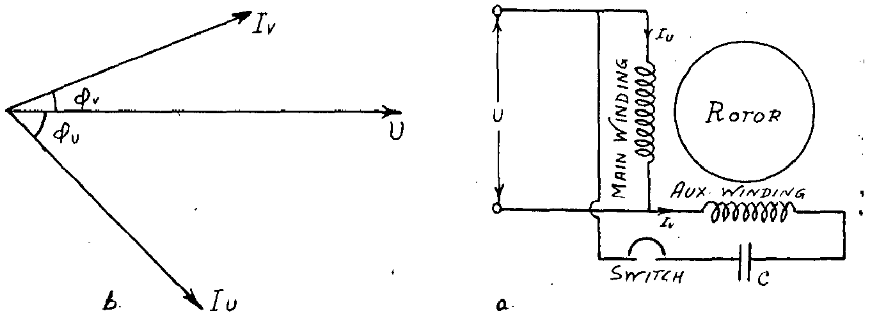


Fig. 2.2.4/a — Capacitor start motor and its Vector diagram.

(ii) Permanent split capacitor motor: These motors may be linked to unbalanced two-phase motors operating from a single phase line. Since both the main winding and the starting winding with the capacitor in series, are connected to the line all the times the motor is in operation. Such motors do not have centrifugal switches or other means of disconnecting the starting winding.

(iii) Capacitor start and Run Motor: In this motor, two value capacitor is used one with higher value for better starting and the other of lower value for normal running conditions. In this way we obtain high starting torque. This fact can be accomplished in two ways. Either by using two seperate capacitors, one being cut out at about 70% of syn. speed by centrifugal switch (fig. 2.2.6.) or use an autotransformer - capacitor unit which provides a higher capacitance effect by giving a higher voltage tap to

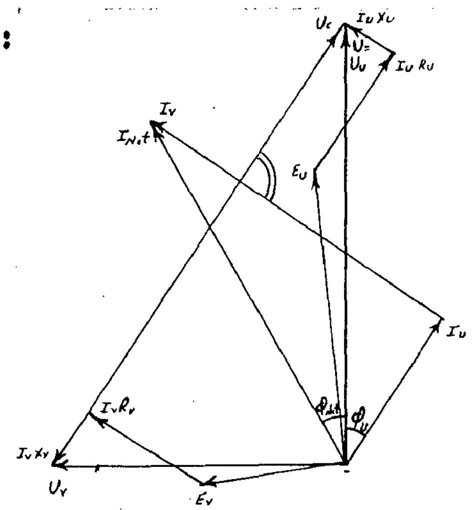


Fig. 2.2.5 — Vector diagram of capacitor motor.

the capacitor at start and lower voltage tap at normal running conditions (fig. 2.2.7.)

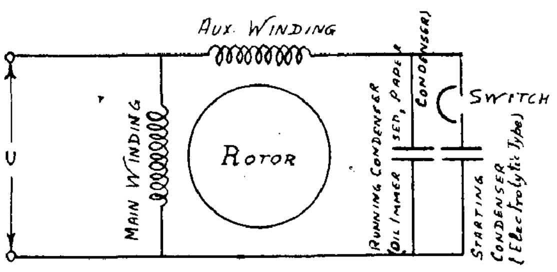


Fig. 2.2.6 —— DOUBLE-VALUE Capacitor motor.

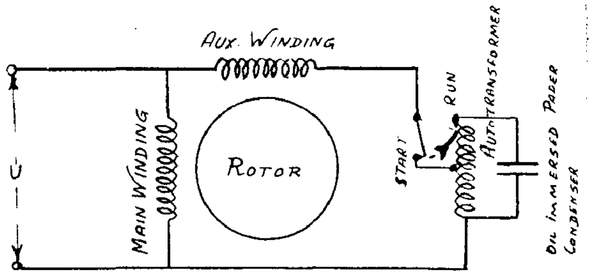


Fig. 2.2.7 —— Capacitor motor with transformer-Capacitor unit.

Calculation of starting torque in a capacitor motor.

As described earlier in the case of Resistance split phase motor, it can be regorously proved (although it is nearly self evident) that in case of a capacitor motor with a condensor of reactance X_c in series of the auxiliary winding.

$$T_s = T_{st} \frac{X_u R_v - R_u (X_v + X_o)}{\alpha (R_v^2 + \overline{X_v + X_o}^2)} \quad — 1$$

and for max.^{m} torque calculations,

$$X_v + X_o = \frac{R_v}{R_u} (X_u \pm Z_u) \quad —— 2$$

and substituting in standstill torque expression,

we have, $$T_{sm} = T_{st} \frac{R_v^2}{R_u^2} \frac{\pm 1}{2\alpha (Z_u \pm X_u)} \quad — 3$$

Here, the value of the max.^{m} torque is much greater if a condenser is used, and since here $X_o = -X_c$

$$T_{sm} = -T_{st} \frac{R_v^2}{R_u^2} \frac{1}{2\alpha (Z_u - X_u)} \quad —— 4$$

Now taking the main winding paramator as constant,

We have $T_{sm} \propto \frac{R_v^2}{\alpha}$

or $T_{sm} \propto R_v^2 N_v$

that is the value of T_{sm} can further be increased by either providing auxiliary winding with more number of turns by increasing its resistance so that the copper ratio of auxiliary winding to the main winding is more, such that $R_V \propto (X_V - X_c)$

2.3 Capacitors.

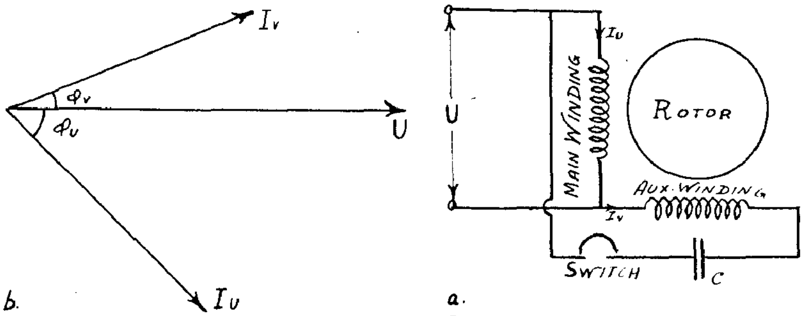


Fig. 2.2.4/b — Capacitor start motor & its Vector diagram.

Alternating current electrolytic capacitors were used for motor starting as earlier as in 1892, but it is only since 1930 that capacitor start motors ha attained commercial importance. It is interesting to note that, in 1896, the repulsion start motor wiped the capacitor start motor out of existance. Now, 50 years later, the capacitor start motor is making the repulsion start motor obsolete for most applications.

The electrolytic capacitors are used for starting purposes but for running purposes, paper capacitors are used. These oil immersed, paper capacitors are bigger and more expensive than the electrolytic type.

A condensor that results in satisfactory running performance for the motor is usually only of small capacity. For Motors of ratings 1/100 to 1 h.p., the condensor values vary from 3 to 50 μF.

2.4 Symmetrical components as applied to split phase two winding motors:

The split phase two winding motors are similar to and may be linked to two phase motors with an unbalance of voltage and winding.

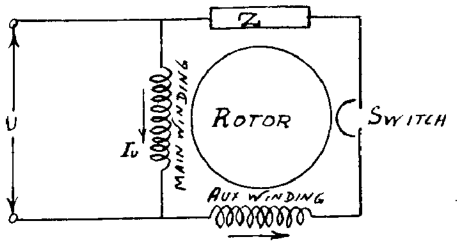
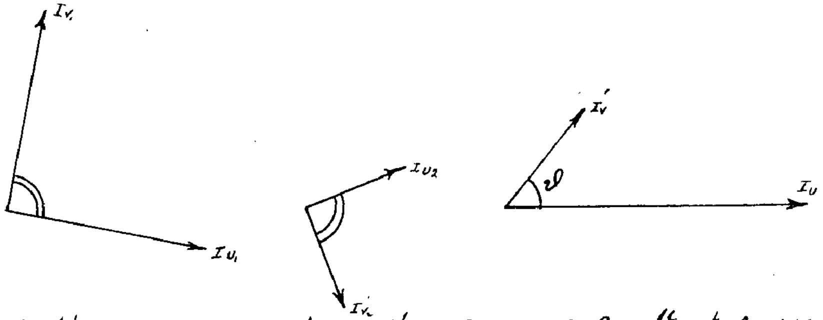


Fig. 2.4.1 — Split-phase motor.



a. +ive phase sequence system.

b. -ive phase-sequence system.

c. Resultant Curren

Fig. 2.4.2

Any system of two phase currents, whether balanced or not, can be resolved into two component systems, each of which is balanced and symmetrical. These systems are called symmetrica components.

The first system is a symmetrical two phase system of currents having normal or positive phase sequence. By this is meant that the current in lines V, U rise to a positive maximum in that order. The second symmetrical group of components has a phase sequence opposite to normal, and is called the negative phase sequence system.

Fig. 2.4.1. shows the vectors of these two components. The vectors I_{v1}' & I_{u_1} from the positive phase sequence components, these both being equal in magnitude and 90 degrees out of phase The phase-sequence is positive, since I_{v_1}' leads I_{u_1}. The vectors I_{v2}' & I_{u2} from the negative phase sequence system, this is also symmetrical but the phase rotation is reversed. The resultant current in line V is given by the vector I_v', which is the vector sum of I_{v_1}' & I_{v2}'. Similarly I_u is the sum of I_{u_1} & I_{u_2}. Any degree of asymmetry can be dealt with in this manner.

The ratio of the negative to the positive phase-sequence component is called the unbalance factor when applied to curren and the asymmetry factor when applied to voltages.

Now $I_v' = I_{v_1}' + I_{v2}'$ ---1

& $I_U = I_{U_1} + I_{U_2}$ ...2

Also, $I'_{V_1} = j\ I_{U_1}$ ...3

& $I'_{V2} = -j\ I_{u2}$ ...4

Therefore,

$I'_V = j(I_{U_1} - I_{U_2})$ ...5

or $I_V = j\alpha(I_{U_1} - I_{U_2})$ ...6

& so, $I_{net} = I_V + I_U$ ...7

or $I_{net} = j\alpha\ (I_{u_1} - I_{u2}) + (I_{u1} + I_{u2})$

or $I_{net} = I_{u1}\ (1 + j\alpha) + I_{u2}\ (1 - j\alpha)$ ...8

Here if Z_1 & Z_2 be the positive & negative phase sequence impedance of the main winding and that of auxiliary winding be $\mathcal{Z}_1$ and $\mathcal{Z}_2$

We have, $I_{u1}Z_1 + I_{u2}\ Z_2 = U_U$ ...9

& $I_{V_1}\mathcal{Z}_1 + I_{V_2}\ \mathcal{Z}_2 = U_V$ ...10

or $(\alpha I'_{V1})\ \left(\frac{Z_1}{\alpha^2}\right) + (\alpha\ I'_{V_2})\ \left(\frac{Z_2}{\alpha^2}\right) = U_V$

or $I'_{V_1} Z_1 + I'_{V_2} Z_2 = \alpha U_V$ — 11 where I'_{V_1}, I'_{V_2}, Z_1 & Z_2

are the transfered values to the main winding side.

or $j\ I_{U_1} Z_1 - jI_{u2}Z_2 = \alpha U_V$

or $I_{U_1}\ Z_1 - I_{U_2}\ Z_2 = -j\alpha U_V$ -12

Solving 9 & 12 for I_{u1} & I_{u2}, we have,

$I_{U_1} = \frac{1}{2Z_1}\ (U_U - j\alpha U_V)$ - 13

& $I_{U_2} = \frac{1}{2Z_2}\ (U_U + j\alpha U_V)$ - 14

Now substituting these values of I_{U_1} & I_{U_2} in equ^n 8, we have,

$$I_{net} = I_{U_1}(1+j\alpha) + I_{U_2}(1-j\alpha)$$

$$= \frac{U_u - j\alpha U_v}{2Z_1}(1+j\alpha) + \frac{U_u + j\alpha U_v}{2Z_2}(1-j\alpha)$$

or $$I_{net} = \frac{1}{2}\left(\frac{1}{Z_1}+\frac{1}{Z_2}\right)(U_u+\alpha^2 U_v) + j\frac{\alpha}{2}\left(\frac{1}{Z_1}-\frac{1}{Z_2}\right)(U_u-U_v) \quad - 15$$

and changing to admittances Y_1, Y_2 for $1/Z_1$ & $1/Z_2$ respectively, we have,

$$I_{net} = \frac{Y_1+Y_2}{2}(U_u+\alpha^2 U_v) + j\alpha\frac{Y_1-Y_2}{2}(U_u-U_v) \quad - 16$$

3. 'RELATIONSHIPS FOR THE CALCULATION OF THE CAPACITOR MOTOR CHARACTERISTICS WITH THE HELP OF DESIGN DATA.

It has been pointed out previously that the performance of the capacitor motor can perhaps best be understood by considering it as a two phase induction motor with unbalanced conditions of voltage and winding. Usually in a capacitor motor, the auxiliary winding in series with a condenser and is in parallel to the main winding, connected directly to the single phase supply (Fig. 3.1.)

Therefore, the respective voltages on the two winding become,

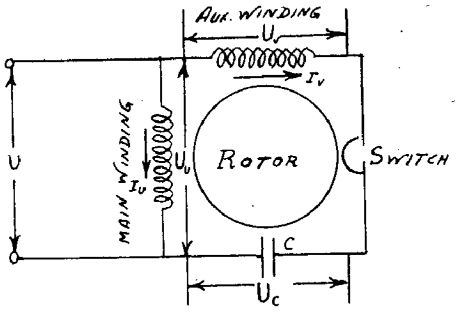


Fig. 3.1. — Capacitor Motor.

$$U_u = U \quad \ldots 1$$

$$U_v = U_u - U_c = U - I_v Z_c - 2$$

$$\text{or } U_v = U - (\alpha I_v')\left(\frac{Z_c'}{\alpha^2}\right)$$

$$= U - \frac{I_v' Z_c'}{\alpha} = U - \frac{I_v'}{\alpha Y_c'}$$

$$\text{or } U_v = U - \frac{j(I_{u_1} - I_{u_2})}{\alpha Y_c'} \quad - 3$$

where $Y_c' = \frac{1}{Z_c'}$, = respective condenser admittance transfered to main winding side.

Also, from the results of chapter 2,

$$I_{u1} = \frac{1}{2z_1}(U_u - j\alpha U_v)$$

$$\text{or } I_{u1} = \frac{Y_1}{2}(U - j\alpha U_v) \quad \ldots 4$$

$$\text{and } I_{u2} = \frac{1}{2z_2}(U_u + j\alpha U_v)$$

$$\text{or } I_{u_2} = \frac{Y_2}{2}(U + j\alpha U_v) \quad \ldots 5$$

Substituting the values of I_{u1} & I_{u2} in equ^n 2, we have,

$$U_v = U - \frac{jU}{\alpha Y_c'}\left(\frac{Y_1 - Y_2}{2}\right) - \frac{U_v}{Y_c'}\left(\frac{Y_1 + Y_2}{2}\right)$$

$$\text{or } U_v\left(1 + \frac{1}{Y_c'}\cdot\frac{Y_1 + Y_2}{2}\right) = U\left(1 - \frac{j}{\alpha Y_c'}\cdot\frac{Y_1 - Y_2}{2}\right)$$

$$\text{or } U_v = U\,\frac{Y_c' - \frac{j}{\alpha}\cdot\frac{Y_1 - Y_2}{2}}{Y_c' + \frac{Y_1 + Y_2}{2}} \quad - 6$$

Now substituting the value of U_V in equ^n. 4 & 5, we have,

$$I_{u1} = \frac{Y_1}{2}\,(U - j\alpha U_V)$$

$$\text{or } I_{U_1} = \frac{UY_1}{2}\;\frac{Y_c'(1-j\alpha) + Y_2}{Y_c' + \frac{Y_1+Y_2}{2}} \qquad -7$$

$$\& \; I_{u2} = \frac{Y_2}{2}\,(U + j\alpha U_V)$$

$$\text{or } I_{U_2} = \frac{UY_2}{2}\;\frac{Y_c'(1+j\alpha) + Y_1}{Y_c' + \frac{Y_1+Y_2}{2}} \qquad -8$$

$$\text{Also, } I_{net} = \frac{Y_1+Y_2}{2}\,(U_U + \alpha^2 U_V) + j\alpha\,\frac{Y_1-Y_2}{2}\,(U_U - U_V)$$

$$= \frac{Y_1+Y_2}{2}\,U\left(1+\alpha^2\,\frac{Y_c' - \frac{j}{\alpha}\,\frac{Y_1-Y_2}{2}}{Y_c' + \frac{Y_1+Y_2}{2}}\right) + j\alpha U\,\frac{Y_1-Y_2}{2}\left(1 - \frac{Y_c' - \frac{j}{\alpha}\,\frac{Y_1-Y_2}{2})}{Y_c' + \frac{Y_1+Y_2}{2}}\right)$$

$$\text{or } I_{net} = U\,\frac{\frac{Y_1+Y_2}{2}\,Y_c'(1+\alpha^2) + Y_1Y_2}{Y_c' + \frac{Y_1+Y_2}{2}} \qquad -9$$

And the voltage across the condenser is,

$$U_c = I_V Z_c = U - U_V = U - U\,\frac{Y_c' - \frac{j}{\alpha}\,\frac{Y_1-Y_2}{2}}{Y_c' + \frac{Y_1+Y_2}{2}}$$

$$\text{or } U_c = U\,\frac{\frac{Y_1+Y_2}{2} + \frac{j}{\alpha}\,\frac{Y_1-Y_2}{2}}{Y_c' + \frac{Y_1+Y_2}{2}} \qquad -10$$

$$\text{Let } U\left(Y_c' + \frac{Y_1+Y_2}{2}\right) = a$$

$$U\left(Y_c'\,\overline{1-j\alpha} + Y_2\right) = b$$

$$U\left(Y_c'\,\overline{1+j\alpha} + Y_1\right) = c$$

$$U\left(\frac{Y_1+Y_2}{2} + \frac{j}{\alpha}\,\frac{Y_1-Y_2}{2}\right) = D$$

$$\& \; U^2\left[\frac{Y_1+Y_2}{2}\,Y_c'(1+\alpha^2) + Y_1Y_2\right] = F$$

we have,

$$I_{u1} = UY_1\cdot\frac{b}{2a} \qquad -11$$

$$I_{u2} = UY2\cdot\frac{c}{2a} \qquad -12$$

$$I_{net} = \frac{F}{a} \qquad -13$$

$$\& \; U = U.\frac{D}{a} \quad \ldots \qquad -14$$

Circle diagram representation of a single phase capacitor motor performance.

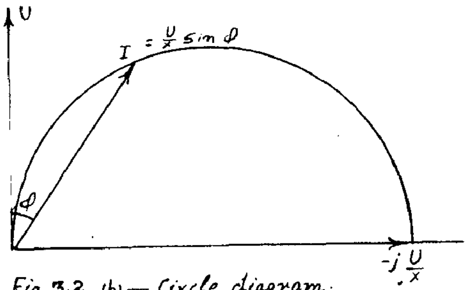


Fig. 3.2 (b) — Circle diagram.

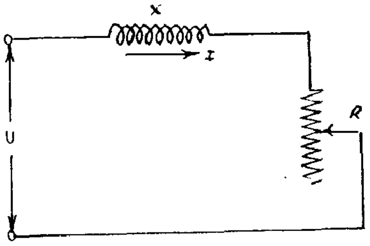


Fig. 3.2 (a) — X, R Circuit.

In any circuit or apparatus with constant reactance and variable power consumption, the current will have a circle locus if the supply voltage is constant (Fig. 3.2.) The induction motor nearly fulfils these conditions and that its current locus is practically the arc of a circle. It was first shown by Heyland in 1894.

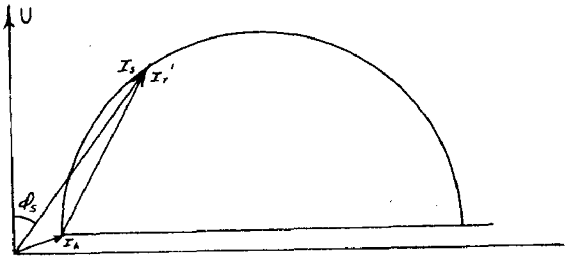


Fig. 3.3 (b) — Induction motor Circle diagram.

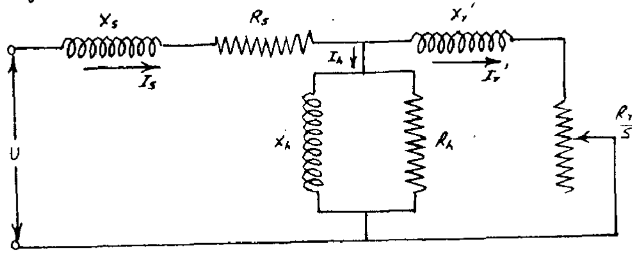


Fig. 3.3 (a) — Induction motor equivalent circuit.

Again it should be noted that the locus of the primary current I_S is a circle provided the inductances involved do not vary with the current. Actually with the large values of the currents, i.e. when the current approaches standstill values, the leakage flux paths may become saturated and if this occurs, inductances decrease, with the result that the current increases beyond the value obtained by assuming no saturation. This will obviously distort the circle diagram and give larger values for the starting torque than are calculated by assuming

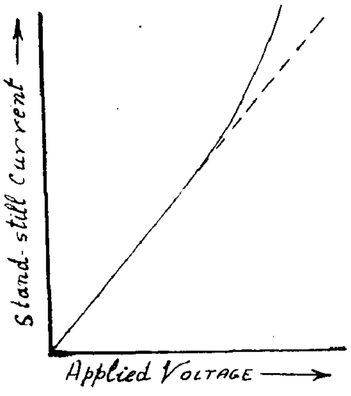


Fig. 3.4.

no saturation. Also increase of eddy current losses in conductors and iron due to large currents will have opposite effect i.e. increased effective resistance and in turn less standstill current and starting torque than are calculated by assuming no such increased losses.

'TORQUE CALCULATIONS FROM CIRCLE DIAGRAM'

The locus of UY1, UY2 & $U\frac{Y_1+Y_2}{2}$ taken at various slips are two circles (Fig.3.6). Now a circle if passes through three known points can be located on a graph. Here, the bigger circle passes from the open circuit point 'O' at slip zero, the short circuit point K at unity slip and infinite slip point ∞ ,and all these three points being known from design data, the circle can be located with its centre M. Again, the smaller circ passes through the short circuit point K of unity slip, infinit slip point ∞ and the centreof the bigger circle M, and all these three points again being ~~haing~~ known, the circle is located with its centre M'.

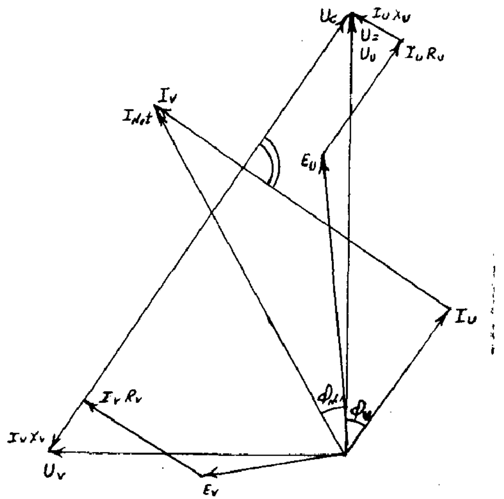
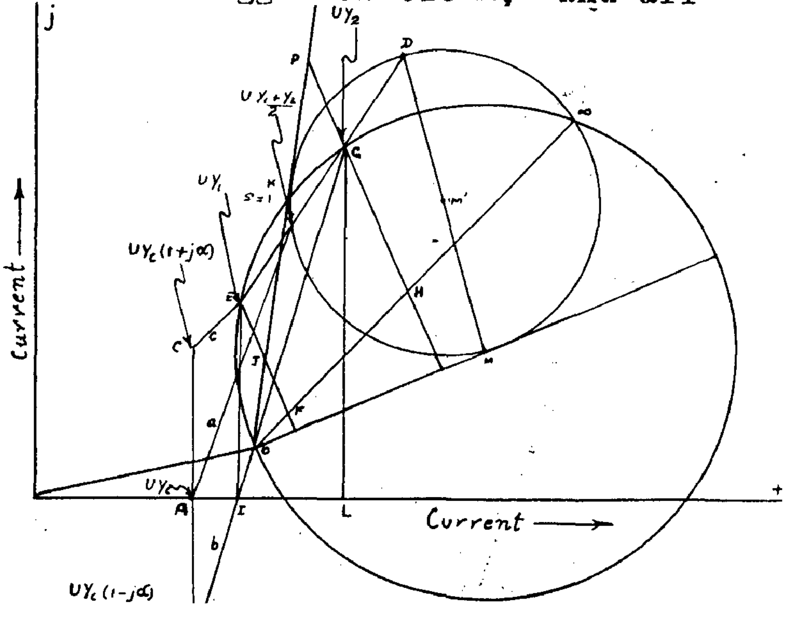


Fig. 3.5 —Vector diagram of Capacitor motor.



The pole D is located by joining the two centres M & M' and extending it to meet the smaller circle. Now any line E G drawn from the pole D to meet the bigger circle at points E & G, the two points correspond to slips s & (2-s) respectively and the mid point of E G falls on the smaller circle and correspond to slip s. In this way various points for different slips are located on the two circle

Now, the various distances E F, G H, E I, E J, G L & G P for input, output & torque calculations and complex variables a, b & c etc. are measured from the circle diagram at various slips and such sets with different condenser reactances are taken.

As the input, output, losses & torque are proportional to the square of the currents, the various quantities will be found out by multiplying the various intercepts for positive phase-sequence & negative phase-sequence values by $(b/2a)^2$ & $(c/2a)^2$ respectively.

Therefore, positive phase-sequence torque at slip s is,

$$T_1 = E\,F(b/2a)^2 \text{ Syn. watts per volt per phase,}$$

& negative phase-sequence torque is,

$$T_2 = -G\,H\,(c/2a)^2 \text{ Syn. watts per volt per phase.}$$

so, total torque per volt per phase is

$$T_{res} = T_1 + T_2 \text{ Syn. watts,}$$

or, torque in net cmKgs. is,

$$T_{net} = T_{res} \times U \times \frac{97.5}{N_s} \times n \quad \text{Cm Kg.}$$

or, $T_{net} = 0{,}13\ U\ T_{res}$ cmKgs. --1 for 4-pole,50c motor.

Similarly, Input $P_i = E\,I(\,b/2a)^2 + GL(C/2a)^2$ - 2 in watts/
/phase.

& total input, $P_i + V_{Fe} = P_i$ + iron losses in watts/Volt/ph
....3

Further, output $P_o = EJ(b/2a)^2 - GP\,(c/2a)^2$.....4
in watts/Volt/phase.

& total output $P_e - V_R = P_o$ − friction & windage losses in watt Volt/phase...5

Also, Losses V = Input − output

i.e. Losses $V = (EI - EJ)\,(b/2a)^2 + (GL + GP)\,(c/2a)^2 +$ iron, friction & windage losses –6 in watts/volt/phas

Efficiency in percent is given by

$$\eta = \frac{\text{output}}{\text{Input}} \times 100 \qquad \ldots.7$$

Also total current input for the motor is

$$I_{net} = U \frac{\frac{Y_1+Y_2}{2}\, Y_c'(1+\alpha^2) + Y_1 Y_2}{Y_c' + \frac{Y_1+Y_2}{2}} \qquad \ldots 8$$

And voltage across the condenser is given by,

$$U_c = U \frac{\frac{Y_1+Y_2}{2} + \frac{j}{\alpha}\,\frac{Y_1-Y_2}{2}}{Y_c' + \frac{Y_1+Y_2}{2}} \qquad \ldots 9$$

4. DETERMINATION OF OPTIMUM VALUES OF THE CAPACITANCES AT VARIOUS SLIPS PERTAINING TO A GIVEN MOTOR.

4.1 Optimum capacitances:

Optimum values of the capacitances of a capacitor motor are those values of the capacitances at which the efficiency and torque characteristics of the motor gives the best performance, that is the efficiency and torque should be the maximum near starting and also near normal running conditions and here giving a nearly flat characteristic at all the slips.

Now for its calculation, we need torque & efficiency Vs. condenser capacities characteristics at various slips ranging from zero to unity. For this, we have to draw the phase-sequence current circle diagram of the motor in order to determine the performance characteristics.

4.2 Calculation of circle diagram paramaters from design data:

Here in order to study the performance characteristic curves of the motor, a problem of a single phase capacitor motor of 1/12 h.p., 50 c, 4-pole, 220 volt is taken with the following design data:

Stator resistance R_s = 47, 5 Ω /phase

Stator leakage reactance X_s = 32, 0 Ω/phase

Rotor resistance transferred to stator side R_r' = 86 Ω /phase

Rotor leakage reactance transfered to stator side X_r' = 34 Ω /phase

Parallel magnatising reactance X_h = 247 Ω /phase

Parallel iron loss resistance (constant), 314 Ω /phase

or total iron loss V_{Fe} net = 30,7 watts

Total friction & windage loss can be assumed to 3 watts.

Turns & copper weight ratio of main to auxiliary windings are unity.

Open circuit point '0'

$$Z_{1_{s=0}} = X_s + X_h - jR_s = 32 + 247 - j47,5 = 279 - j47,5$$

$$\text{or } I_{1_{s=0}} = UY_1 = \frac{220\ (279 + j\ 47,\ 5)}{279^2 + 47,5^2} = \frac{220(279 + j\ 47,5)}{77800 + 2250}$$

$$= 0,77 + j\ 0,12$$

Infinite slip point '∞'

$$Z1_{s=\infty} = X_s + \frac{X_h \cdot X_r'}{X_h + X_r'} - j\,R_s$$

$$= 32 + \frac{247\ .\ 34}{281} - j47,5 = 61,9 - j47,5$$

$$\text{or } I_{1_{s=\infty}} = UY_1 = \frac{220(61,9 + j47,5)}{61,9^2 + 47,5^2} = \frac{220(61,9 + j\ 47,5)}{3830 + 2260}$$

$$= 2,24 + j\ 1,71$$

Centre of the bigger circle '$\overline{M}$'

the coordinates of M are given by

$$m_1 = U\,\frac{1/2\,(X_h + X_r'{}_{s=\infty}) + X_s + j\,R_s}{(X_s + X_r'{}_{s=\infty})\,(X_s + X_h) + R_s^2}$$

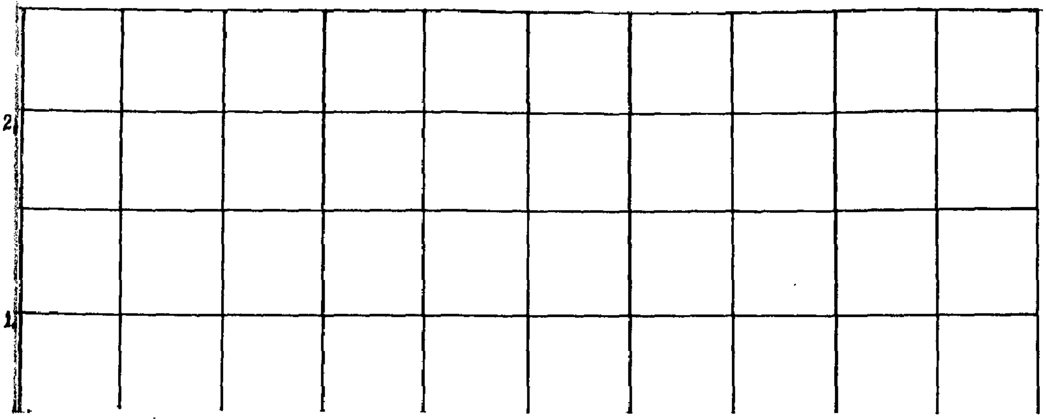
$$= 220\,\frac{1/2\,(276,9) + 32 + j\,47,\ 5}{61,9 \cdot 279 + 2260} = 220\ \frac{170,45 + j\,47,5}{19560}$$

$$= 1,92 + j\ 0,535$$

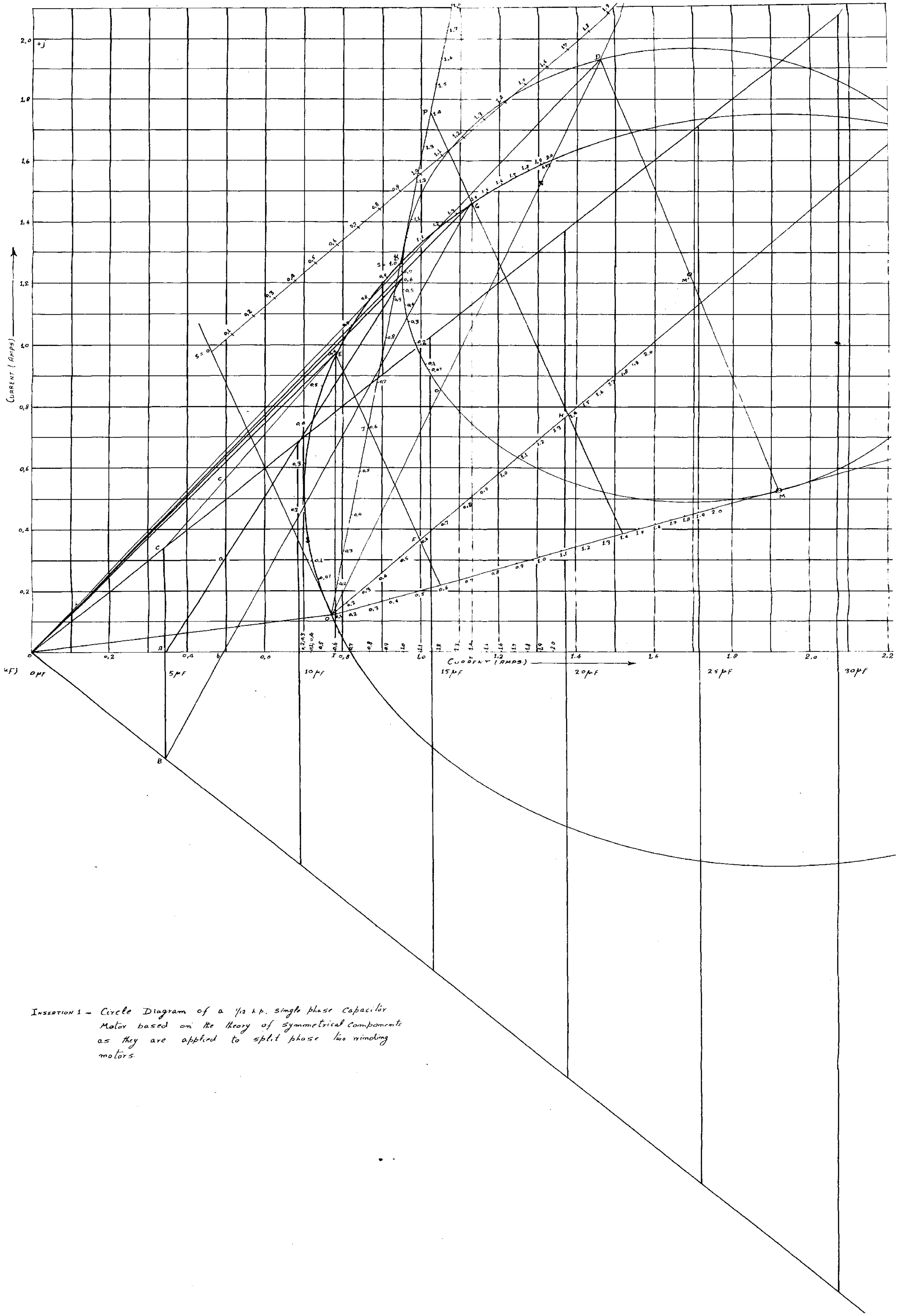
Hence, the two circles are drawn and circle diagram (In-section No.1) completed.

Now various slip points on the two circles are located by the usual method and capacitance lines for capacitances 0, 5, 10 15, 20, 25, 30 μF are drawn.

INSERTION No I



Ins. No.——— Current Circle diagram of a 1/12 h.p., 220 Volt, 4-pole, 50 ~, c-Motor based on the theory of symmetrical components as they are applied to split-phase two winding motors.



Insertion 1 – Circle Diagram of a 1/12 h.p. single phase Capacitor Motor based on the theory of symmetrical components as they are applied to split phase two winding motors.

Now as described in Chapter 3, the positive phase sequenc torque at slip s is given by

$$T_1 = EF\ (b/2a)^2 \text{ syn. watts/volt/phase}$$

& similarly, the negative phase- sequence torque is

$$T_2 = -GH\ (c/2a)^2 \text{ syn. watts/Volt/phase}$$

So, the total torque is

$$T_{res} = T_1 + T_2 \text{ syn. watts/Volt/phase}$$

& net torque in cm Kgs. is

$$Tnet = Tres \times U \times \frac{97.5}{1500} \times 2 = 0{,}13\ U\ T_{res}$$

& for 220 Volt supply

$$T_{net} = 0{,}13 \times 220\ T_{res}$$

or $T_{net} = 28{,}6\ T_{res}$ cm Kgs.

The results have been plotted in Table I. The torque Vs. capacitance characteristic at various slips is drawn with the values of torque at various slips determined from table I, a-nd capacitances for maximum torque at each slip is found & tabulated in table II. (Graph I & II).

TABLE I

ibulation of various intercepts and calculation of torque produced at various slips & capacities.

S $0\,\mu F$	0,0	0,1	0,2	0,3	0,4	0.5	0,6	0.7	0,8	0,9	1,0
c	0,782	0,783	0,846	0,936	1,035	1,145	1,249	1,35	1,442	1,528	1,605
a	1,362	1,382	1,412	1,450	1,486	1,520	1,548	1,565	1,580	1,592	1,605
b	2,092	2,060	2,026	1,985	1,942	1,900	1,854	1,798	1,742	1,675	1,605
$2a$	2,724	2,764	2,824	2,900	2,972	3,040	3,096	3,130	3,160	3,184	3,210
$\frac{b}{2a}$	0,768	0,746	0,718	0,684	0,653	0,625	0,599	0,574	0,552	0,527	0,500
$(\frac{b}{2a})^2$	0,590	0,557	0,517	0,468	0,427	0,390	0,359	0,329	0,304	0,277	0,250
$\frac{c}{2a}$	0,287	0,283	0,2995	0,323	0,348	0,377	0,403	0,432	0,456	0,480	0,500
$(\frac{c}{2a})^2$	0,0825	0,0803	0,0898	0,1042	0,121	0,142	0,1625	0,186	0,208	0,231	0,250
$5\,\mu F$ c	0,483	0,382	0,379	0,450	0,550	0,660	0,765	0,868	0,965	1,050	1,133
a	1,113	1,154	1,200	1,250	1,290	1,329	1,363	1,383	1,400	1,413	1,428
b	2,195	2,165	2,134	2,098	2,059	2,018	1,973	1,920	1,870	1,808	1,737
$2a$	2,226	2,308	2,400	2,500	2,580	2,658	2,726	2,766	2,800	2,826	2,856
$\frac{b}{2a}$	0,985	0,938	0,888	0,838	0,798	0,759	0,723	0,694	0,668	0,638	0,608
$(\frac{b}{2a})^2$	0,972	0,880	0,788	0,704	0,637	0,577	0,523	0,482	0,446	0,408	0,369
$\frac{c}{2a}$	0,217	0,1655	0,158	0,180	0,213	0,248	0,281	0,314	0,345	0,371	0,397
$(\frac{c}{2a})^2$	0,047	0,0273	0,025	0,0324	0,0455	0,0617	0,0787	0,0985	0,119	0,138	0,1575
$= 10\,\mu F$ c	0,577	0,392	0,227	0,075	0,062	0,190	0,300	0,404	0,498	0,581	0,657
a	0,936	0,992	1,052	1,115	1,162	1,212	1,245	1,270	1,290	1,303	1,314
b	2,389	2,356	2,331	2,304	2,271	2,234	2,193	2,153	2,104	2,047	1,987
$2a$	1,872	1,984	2,104	2,230	2,340	2,424	2,490	2,540	2,580	2,606	2,608
$\frac{b}{2a}$	1,276	1,188	1,108	1,033	0,977	0,922	0,891	0,847	0,815	0,786	0,756
$(\frac{b}{2a})^2$	1,630	1,410	1,230	1,070	0,955	0,850	0,794	0,718	0,664	0,618	0,572
$\frac{c}{2a}$	0,308	0,1975	0,1078	0,0337	0,0267	0,0784	0,1205	0,159	0,193	0,223	0,250
$(\frac{c}{2a})^2$	0,095	0,039	0,0116	0,00112	0,00071	0,00615	0,0145	0,0253	0,0373	0,0497	0,0625

TABLE II Contd.

Tabulation of various ~~slop~~ intercepts & Calculation of torque produced at various slips & capacities C

S C = 15 μF	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
C	0,953	0,800	0,660	0,533	0,431	0,338	0,263	0,220	0,212	0,227	0,272
a	0,863	0,942	1,013	1,082	1,135	1,182	1,220	1,242	1,265	1,277	1,290
b	2,660	2,637	2,614	2,588	2,562	2,530	2,498	2,455	2,418	2,368	2,317
2a	1,726	1,884	2,026	2,164	2,270	2,364	2,440	2,484	2,530	2,554	2,580
$\frac{b}{2a}$	1,543	1,400	1,290	1,194	1,130	1,080	1,023	0,988	0,956	0,928	0,897
$(\frac{b}{2a})^2$	2,380	1,960	1,663	1,427	1,290	1,165	1,048	0,978	0,915	0,862	0,806
$\frac{c}{2a}$	0,553	0,424	0,3255	0,2465	0,190	0,143	0,1078	0,0886	0,0838	0,0888	0,1053
$(\frac{c}{2a})^2$	0,305	0,181	0,106	0,0607	0,0362	0,0205	0,0116	0,00785	0,00702	0,0079	0,0111
C = 20 μF C	1,402	1,270	1,144	1,027	0,923	0,828	0,734	0,645	0,570	0,502	0,437
a	0,918	1,007	1,087	1,155	1,205	1,257	1,287	1,310	1,330	1,347	1,356
b	2,990	2,963	2,947	2,927	2,906	2,878	2,850	2,820	2,780	2,742	2,696
2a	1,836	2,014	2,174	2,310	2,410	2,514	2,574	2,620	2,660	2,694	2,712
$\frac{b}{2a}$	1,630	1,470	1,356	1,268	1,207	1,145	1,107	1,076	1,045	1,018	0,995
$(\frac{b}{2a})^2$	2,660	2,170	1,840	1,610	1,455	1,310	1,247	1,160	1,094	1,035	0,99
$(\frac{c}{2a})$	0,764	0,631	0,527	0,444	0,383	0,329	0,285	0,246	0,214	0,1864	0,1612
$(\frac{c}{2a})^2$	0,583	0,398	0,277	0,1975	0,147	0,1086	0,0814	0,0606	0,0458	0,0347	0,026
C = 25 μF C	1,864	1,742	1,621	1,512	1,410	1,303	1,210	1,115	1,036	0,962	0,887
a	1,091	1,181	1,253	1,318	1,363	1,410	1,443	1,460	1,480	1,490	1,500
b	3,352	3,340	3,320	3,302	3,284	3,262	3,236	3,210	3,180	3,142	3,100
2a	2,182	2,362	2,506	2,636	2,726	2,820	2,886	2,920	2,960	2,980	3,000
$\frac{b}{2a}$	1,535	1,414	1,323	1,253	1,205	1,156	1,120	1,100	1,076	1,053	1,032
$(\frac{b}{2a})^2$	2,355	2,00	1,75	1,570	1,450	1,340	1,255	1,210	1,155	1,110	1,066
$\frac{c}{2a}$	0,854	0,737	0,647	0,573	0,517	0,462	0,419	0,382	0,350	0,323	0,2955
$(\frac{c}{2a})^2$	0,730	0,543	0,418	0,328	0,267	0,213	0,1755	0,146	0,1225	0,1045	0,0875

TABLE II contd.

Tabulation of various intercepts and Calculation of torque produced at various slips & capacities.

S $C = 30\,\mu F$	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
C	2,35	2,235	2,117	2,000	1,900	1,800	1,704	1,610	1,524	1,448	1,372
a	1,337	1,413	1,486	1,540	1,586	1,623	1,652	1,670	1,684	1,695	1,700
b	3,748	3,732	3,722	3,705	3,692	3,668	3,652	3,63	3,603	3,568	3,533
$2a$	2,674	2,826	2,972	3,080	3,172	3,246	3,304	3,340	3,368	3,390	3,400
$\frac{b}{2a}$	1,403	1,320	1,252	1,203	1,164	1,130	1,104	1,087	1,070	1,053	1,035
$(\frac{b}{2a})^2$	1,970	1,745	1,570	1,450	1,355	1,275	1,212	1,185	1,145	1,105	1,080
$\frac{c}{2a}$	0,880	0,791	0,712	0,649	0,598	0,554	0,516	0,482	0,453	0,427	0,403
$(\frac{c}{2a})^2$	0,775	0,625	0,507	0,422	0,358	0,307	0,266	0,232	0,204	0,1825	0,163
UY_1	0,770 +j0,120	0,720 +j0,30	0,710 +j0,465	0,710 +j0,617	0,718 +j0,743	0,746 +j0,866	0,782 +j0,972	0,822 +j1,068	0,869 +j1,150	0,912 +j1,222	0,956 +j1,28
$\lvert UY_1 \rvert$	0,182	0,783	0,846	0,936	1,035	1,450	1,249	1,350	1,442	1,528	1,605
UY_2	1,344 +j1,612	1,310 +j1,590	1,278 +j1,570	1,242 +j1,550	1,207 +j1,526	1,170 +j1,488	1,130 +j1,468	1,090 +j1,430	1,048 +j1,389	1,003 +j1,340	0,956 +j1,28
$\lvert UY_2 \rvert$	2,092	2,060	2,026	1,985	1,942	1,900	1,854	1,798	1,742	1,675	1,605
$U\frac{Y_1+Y_2}{2}$	1,055 +j0,857	1,013 +j0,938	0,987 +j1,010	0,970 +j1,078	0,960 +j1,130	0,955 +j1,180	0,953 +j1,215	0,951 +j1,240	0,951 +j1,260	0,953 +j1,275	0,956 +j1,28
$\lvert U\frac{Y_1+Y_2}{2} \rvert$	1,362	1,382	1,412	1,450	1,486	1,520	1,548	1,565	1,580	1,592	1,605
$U\frac{Y_1-Y_2}{2}$	-0,289 -j0,755	-0,207 -j0,652	-0,291 -j0,56	-0,272 -j0,472	-0,247 -j0,396	-0,215 j0,308	-0,177 -j0,253	-0,139 -j0,190	-0,097 -j0,129	0,050 -j0,065	0,00
$\lvert U\frac{Y_1-Y_2}{2} \rvert$	0,793	0,702	0,622	0,538	0,462	0,385	0,302	0,220	0,145	0,074	0,00
$jU\frac{Y_1-Y_2}{2}$	0,755 -j0,289	0,652 -j0,207	0,560 -j0,291	0,472 -j0,272	0,396 -j0,247	0,308 -j0,215	0,253 -j0,177	0,190 -j0,139	0,129 -j0,097	0,065 -j0,050	0,00
$U\frac{Y_1+Y_2}{2}+jU\frac{Y_1-Y_2}{2}$ $= D$ (say)	1,818 +j0,568	1,665 +j0,731	1,547 +j0,719	1,442 +j0,806	1,356 +j0,883	1,263 +j0,965	1,206 +j1,038	1,141 +j1,101	1,080 +j1,163	1,018 +j1,225	0,956 +j1,288
$\lvert D \rvert$	1,982	1,818	1,703	1,652	1,62	1,592	1,592	1,592	1,587	1,593	1,604
$UY_1 \times UY_2$	0,8765 +j1,4033	0,4556 +j1,536	0,1775 +j1,708	-0,0740 +j1,867	-0,268 +j1,991	-0,415 +j2,123	-0,544 +j2,244	-0,681 +j2,337	-0,685 +j2,412	-0,721 +j2,447	-0,742 +j2,46
EF	0,000	0,180	0,322	0,437	0,525	0,592	0,642	0,682	0,710	0,730	0,740
$-GH$	-0,670	-0,680	-0,692	0,704	-0,714	0,723	-0,732	-0,740	-0,742	-0,743	-0,740
EI	0,120	0,300	0,465	0,617	0,743	0,866	0,972	1,068	1,150	1,222	1,288
GL	1,612	1,590	1,570	1,550	1,526	1,488	1,468	1,430	1,389	1,340	1,2880

TABLE I contd

Tabulation of various intercepts and Calculation of torque produced at various slips & capacities

S	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
EJ	0,000	0,160	0,257	0,307	0,317	0,298	0,258	0,204	0,138	[illegible]	0,000
−GP	−0,683	−0,620	−0,560	−0,500	−0,432	−0,363	−0,300	−0,227	−0,152	−0,077	0,000
C = 0 µF $T_1 = EF(\frac{b}{2a})^2$ S·Watts	0,000	0,1003	0,1665	0,2045	0,224	0,2307	0,2307	0,2245	0,216	0,2025	0,185
$T_2 = -GH(\frac{c}{2a})^2$ S·Watts	−0,0553	−0,0546	−0,0621	−0,0733	−0,0863	−0,1053	−0,1189	−0,1375	−0,1543	−0,1717	−0,185
$T_{res} = T_1 + T_2$ S·Watts	−0,0553	0,0457	0,1044	0,1312	0,1377	0,1254	0,1118	0,0870	0,0617	0,0308	0,000
$T_{Net} = 28{,}6 \cdot T_{res}$ cm Kgs	−1,580	1,310	2,980	3,760	3,940	3,590	3,200	2,490	1,770	0,880	0,000
C = 5 µF $T_1 = EF(\frac{b}{2a})^2$ S Watts	0,000	0,1584	0,2535	0,3075	0,3345	0,3415	0,3355	0,3289	0,3165	0,2980	0,2730
$T_2 = -GH(\frac{c}{2a})^2$ S Watts	−0,0315	−0,0186	−0,0173	−0,0228	−0,0325	−0,0446	−0,0576	−0,0728	−0,0883	−0,1025	−0,1167
$T_{res} = T_1 + T_2$ S Watts	−0,0315	0,1398	0,2362	0,2847	0,3020	0,2969	0,2779	0,25[illegible]	0,2282	0,1955	0,1563
$T_{Net} = 28{,}6 \cdot T_{res}$ cm Kgs.	−0,900	4,000	6,760	8,140	8,640	8,490	7,940	7,320	6,530	5,590	4,470
C = 10 µF $T_1 = EF(\frac{b}{2a})^2$ S·Watts	0,000	0,2535	0,396	0,4675	0,5015	0,5035	0,5095	0,4830	0,4715	0,4510	0,4230
$T_2 = -GH(\frac{c}{2a})^2$ S Watts	−0,0637	−0,0265	−0,008	−0,0008	−0,0005	−0,0044	0,0,06	−0,0187	−0,0276	−0,0369	−0,0463
$T_{res} = T_1 + T_2$ S·Watts	−0,0637	0,227	0,388	0,4667	0,5010	0,4991	0,4989	0,4643	0,4439	0,4141	0,3767
$T_{Net} = 28{,}6 \cdot T_{res}$ cm Kgs.	−1,82	6,49	11,12	13,37	14,33	14,29	14,28	13,29	12,71	11,84	10,78
C = 15 µF $T_1 = EF(\frac{b}{2a})^2$ S Watts	0,000	0,3525	0,536	0,623	0,677	0,6895	0,6730	0,667	0,650	0,629	0,597
$T_2 = -GH(\frac{c}{2a})^2$ S·Watts	−0,2042	−0,1830	−0,0755	−0,0427	−0,0259	−0,0148	−0,0085	−0,0058	−0,0052	−0,0059	−0,0082
$T_{res} = T_1 + T_2$ S Watts	−0,2042	0,1695	0,4605	0,5803	0,6511	0,6747	0,6645	0,6612	0,6448	0,6231	0,5888
$T_{Net} = 28{,}6\ T_{res}$ cm Kgs.	−5,84	4,85	13,18	16,61	18,62	19,29	19,02	18,91	18,45	17,83	16,85
C = 20 µF $T_1 = EF(\frac{b}{2a})^2$ S·Watts	0,000	0,3905	0,593	0,703	0,763	0,775	0,800	0,791	0,777	0,756	0,733
$T_2 = -GH(\frac{c}{2a})^2$ S Watts	−0,3905	−0,2705	−0,1914	−0,139	−0,105	−0,0785	0,0596	−0,0448	−0,034	−0,0258	−0,0193
$T_{res} = T_1 + T_2$ S Watts	−0,3905	0,120	0,4016	0,564	0,658	0,6965	0,7404	0,7462	0,743	0,7302	0,7137
$T_{Net} = 28{,}6 \cdot T_{res}$ cm Kgs.	−11,17	3,43	11,48	16,13	18,83	19,92	21,20	21,35	21,26	20,90	20,44
C = 25 µF $T_1 = EF(\frac{b}{2a})^2$ S·Watts	0,000	0,360	0,564	0,686	0,761	0,793	0,812	0,825	0,820	0,810	0,789
$T_2 = -GH(\frac{c}{2a})^2$ S Watts	−0,489	−0,3695 ~~−0,0096~~	−0,299 ~~0,265~~	−0,231 0,~~455~~	−0,1907 ~~0,5203~~	−0,154 ~~0,639~~	−0,1283 ~~0,6837~~	−0,108 ~~0,717~~	−0,0908 ~~0,7292~~	−0,0776	−0,0648

TABLE **I** contd

Tabulation of various intercepts and Calculation of torque produced at various slips & capacities co

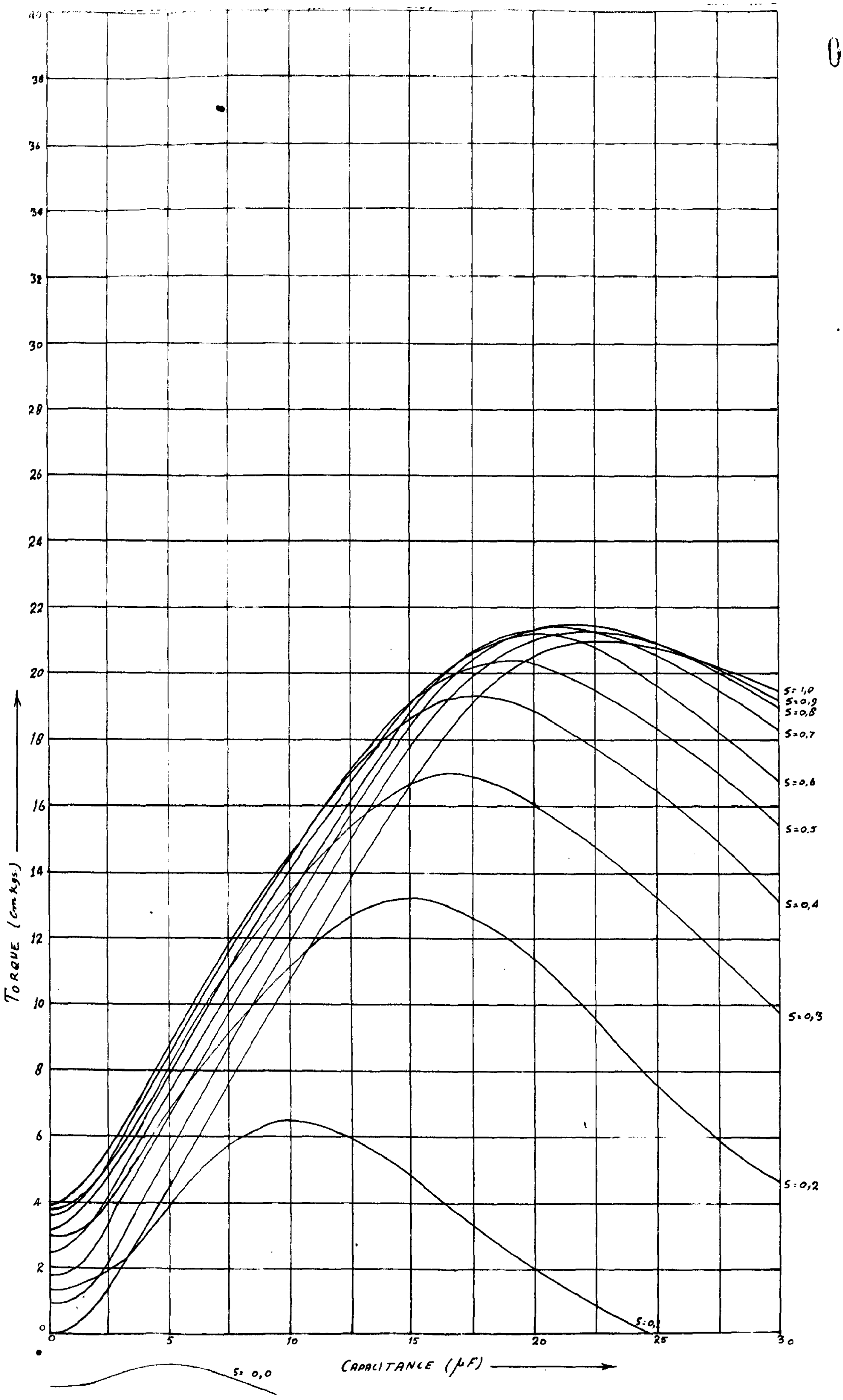
$T_{res} = \frac{T_1+T_2}{S}$ Watts	0,409	0,0095	0,265	0,455	0,5103	0,639	0,6837	0,717	0,7292	0,7324	[illegible]
$T_{Net} = 28.6\ T_{res}$ cm Kgs	14,00	0,27	7,58	13,02	16,33	18,27	19,56	20,52	20,86	20,95	20,70
C = 30 μF $T_1 = EF(\frac{b}{2a})^2$ S Watts	0,000	0,314	0,506	0,633	0.711	0,755	0,778	0,808	0,813	0,806	[illegible]
$T_2 = -GH(\frac{c}{2a})^2$ S Watts	-0,519	-0,425	0,351	-0,297	-0,256	-0,222	-0,1947	-0,1717	-0,1513	-0,1355	-0,120
$T_{res} = \frac{T_1+T_2}{S}$ Watts	0,519	,111	0,155	0,336	0,455	0,533	0,5833	0,6363	0,6617	0,6705	0,679
$T_{Net} = 28,6\ T_{res}$ cm Kgs	-14,87	-3,18	4,43	9,61	13,02	15,25	16,67	18,21	18,92	19,18	19,43
S	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0

From the torque Vs capacitance characteristic (Graph I), the values of capacitan giving peak value Torques at various slips are tabulated below and then the voltage acr the condenser are calculated (Table **II** & graph II).

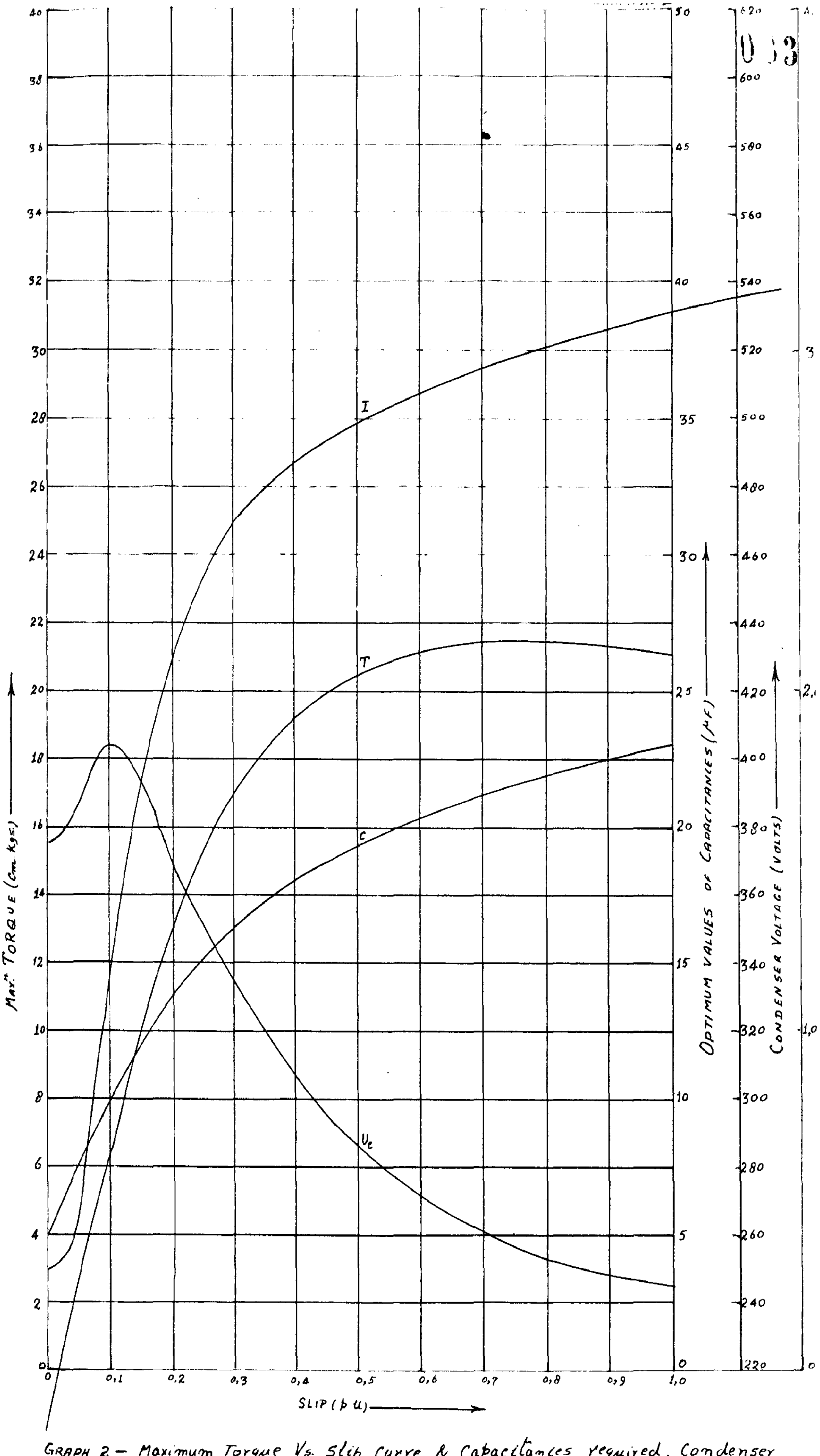
Tabulation of capacitances for max^m: torques at various particular slips. (see graph Nos. I & II)

TABLE **II**

S	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
C(OPTIMUM) μF	5,0	10,0	14,0	16,5	18,0	19,25	20,25	21,25	22,0	22,5	23,0
T(OPTIMUM) cm Kgs	-0,90	6,49	13,18	17,00	19,30	20,40	21,20	21,40	21,42	21,24	21,0
UY_c'	-0,345	-0,691	-0,967	-1,140	-1,243	-1,330	-1,398	-1,468	-1,519	-1,553	-1,58
$U\frac{Y_1+Y_2}{2}$	1,055 +j 0,857	1,013 +j 0,938	0,987 +j 1,01	0,970 +j 1,018	0,960 +j 1,130	0,955 +j 1,180	0,953 +j 1,215	0,951 +j 1,240	0,951 +j 1,260	0,953 +j 1,275	0,956 +j 1,28
$U\frac{Y_1-Y_2}{2}$	-0,289 -j 0,755	-0,207 -j 0,652	-0,291 -j 0,560	-0,272 -j 0,472	-0,247 -j 0,396	-0,215 -j 0,308	-0,177 -j 0,253	-0,139 -j 0,190	-0,097 -j 0,129	-0,050 -j 0,066	0,00
$jU\frac{Y_1-Y_2}{2}$	0,755 -j 0,289	0,652 -j 0,207	0,560 -j 0,291	0,472 -j 0,272	0,396 j 0,247	0,308 j 0,215	0,253 -j 0,177	0,190 -j 0,139	0,129 -j 0,097	0,066 -j 0,050	0,000
$U\frac{Y_1+Y_2}{2}+jU\frac{Y_1-Y_2}{2}$ D	1,810 +j 0,568	1,665 +j 0,731	1,547 +j 0,719	1,442 +j 0,806	1,356 +j 0,883	1,263 +j 0,965	1,206 +j 1,038	1,141 +j 1,101	1,080 +j 1,163	1,018 +j 1,225	0,956 +j 1,28
|D|	1,898	1,818	1,703	1,652	1,617	1,590	1,591	1,590	1,588	1,592	1,602
a at C OPTIMUM	1,113	0,992	1,013	1,086	1,162	1,240	1,288	1,342	1,382	1,410	1,433
$U_c = \frac{220\ D}{a}$ Volts	374,5	404,0	369,5	335,3	306,0	283,5	271,5	260,5	252,8	248,5	245,5



Graph 1 — Torque Vs. Capacitance Curves at Various Slips.



GRAPH 2 – Maximum Torque Vs. Slip Curve & Capacitances required, Condenser Voltage and motor input Current at these values of Torques.

Also, efficiency in percent is given by

$$\eta = \frac{\text{Net output/Volt/ phase}}{\text{Net input/Volt/phase}} \times 100$$

& Net output/Volt/phase $= EJ\,(b/2a)^2 - GP(c/2a)^2 - V_R$

& Net input/Volt/phase $= EI(b/2a)^2 + GL\,(c/2a)^2 + V_{Fe}$

here, $EJ\,(b/2a)^2$, $-GH(c/2a)^2$, $EI\,(b/2a)^2$ & $GL\,(c/2a)^2$ are found from the circle diagram intercepts and tabulated in table III, the total friction & windage losses being assumed to be 3 watts,

Therefore V_R = friction & windage losses/Volt/phase

or $V_R = \frac{3}{2 \times 220} = 0{,}0068$ watts,

& the total iron losses are given to be constant and equal to 30 watts,

So,

$$V_{Fe} = \frac{30{,}7}{2 \times 220} = 0{,}07 \text{ watts.}$$

Therefore,

$Po_{res} = P_o - 0{,}0068$ watts/Volt/phase

& $Pi_{res} = P_i + 0{,}07$ watts/Volt/phase

& $\eta = \frac{Po_{res}}{Pi_{res}} \times 100$

or $\eta = \frac{Po - 0{,}0068}{Pi + 0{,}07} \times 100$

TABLE III

Calculation of efficiencies at various slips & capacities. (See graph Nos. III & IV)

S	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
$C = 0\ \mu F$ $EI(\frac{b}{2a})^2$	0,0708	0,1672	0,2405	0,2885	0,3175	0,3375	0,3485	0,3515	0,349	0,3385	0,322
$GL(\frac{c}{2a})^2$	0,133	0,1277	0,1409	0,1614	0,1847	0,2115	0,2385	0,266	0,2988	0,309	0,322
P_i	0,2038	0,2949	0,3814	0,4499	0,5022	0,549	0,587	0,6175	0,6478	0.6475	0,644
$P_i + 0,07$	0,2738	0,3649	0,4514	0,5199	0,5722	0,619	0,657	0,6875	0,7178	0,7175	0,714
$EJ(\frac{b}{2a})^2$	0,000	0.0892	0,133	0,1435	0,1354	0,116	0,0925	0,0671	0,0418	0,0213	0,000
$-GP(\frac{c}{2a})^2$	-0,0563	-0,0498	-0,0502	-0,0521	-0,0552	-0,0516	-0,0488	-0,0422	-0,0327	-0,0178	0,000
P_o	-0,0563	0,0394	0,0828	0,0914	0,0802	0,0644	0,0437	0,0249	0,0091	0,0035	0,000
$P_o - 0,0068$	-0,0631	0,0326	0,076	0,0846	0,0734	0,0576	0,0369	0,0181	0,0023	0,000	0,000
η per Cent	-23,0	9,0	16,8	16,6	12,8	9,3	5,6	2,6	0,3	0,0	0,0
$C = 5\ \mu F$ $EI(\frac{b}{2a})^2$	0,1166	0,264	0,3665	0,434	0,473	0,500	0,508	0,515	0,5125	0,500	0,475
$GL(\frac{c}{2a})^2$	0,0758	0,0434	0,0392	0,0502	0,0794	0,0918	0,1155	0,1407	0,1652	0,185	0,2026
P_i	0,1924	0,3074	0,4057	0,4842	0,5524	0,5918	0,6235	0,6557	0,6777	0,685	0,6776
$P_i + 0,07$	0,2624	0,3774	0,4757	0,5542	0,6224	0,6618	0,6935	0,7257	0,7477	0,755	0,7476
$EJ(\frac{b}{2a})^2$	0,000	0,1407	0,2025	0,2155	0,202	0,172	0,135	0,0983	0,0615	0,0315	0,000
$-GP(\frac{c}{2a})^2$	-0,0321	-0,0169	-0,0139	-0,0162	-0,0225	-0,0224	-0,0238	-0,0223	-0,0181	-0,0106	0,000
P_o	-0,0321	0,1238	0,1886	0,1993	0,1795	0,1496	0.1112	0,076	0,0434	0,0209	0,000
$P_o - 0,0068$	-0,0389	0,117	0,1818	0,1925	0,1727	0,1428	0,1044	0,0692	0,0366	0,0141	0,000
η per Cent	-14,8	31,0	38,2	34,7	27,7	21,6	15,1	9,5	4,9	1,9	0,0
$C = 10\ \mu F$ $EI(\frac{b}{2a})^2$	0,1955	0,423	0,572	0,660	0,710	0,736	0,771	0,767	0.763	0,755	0,737
$GL(\frac{c}{2a})^2$	0,153	0,062	0,0182	0,0017	0,0011	0,0092	0,0213	0,0362	0,0518	0,0665	0.0805
P_i	0,3485	0,485	0,5902	0,6617	0.7111	0,7452	0.7923	0,8032	0,8148	0,8215	0,8175
$P_i + 0,07$	0.4185	0,555	0,6602	0,7317	0,7811	0.8152	0,8623	0.8732	0,8848	0,8915	0.8875
$EJ(\frac{b}{2a})^2$	0,000	0,2255	0,316	0,3285	0,303	0,253	0,2048	0,1463	0,0915	0.0476	0.000
$-GP(\frac{c}{2a})^2$	-0,0648	-0,0242	-0,0065	-0,0006	-0,0003	-0,0022	-0,0044	-0,0058	-0,0057	-0,0038	0,000

TABLE III Contd.

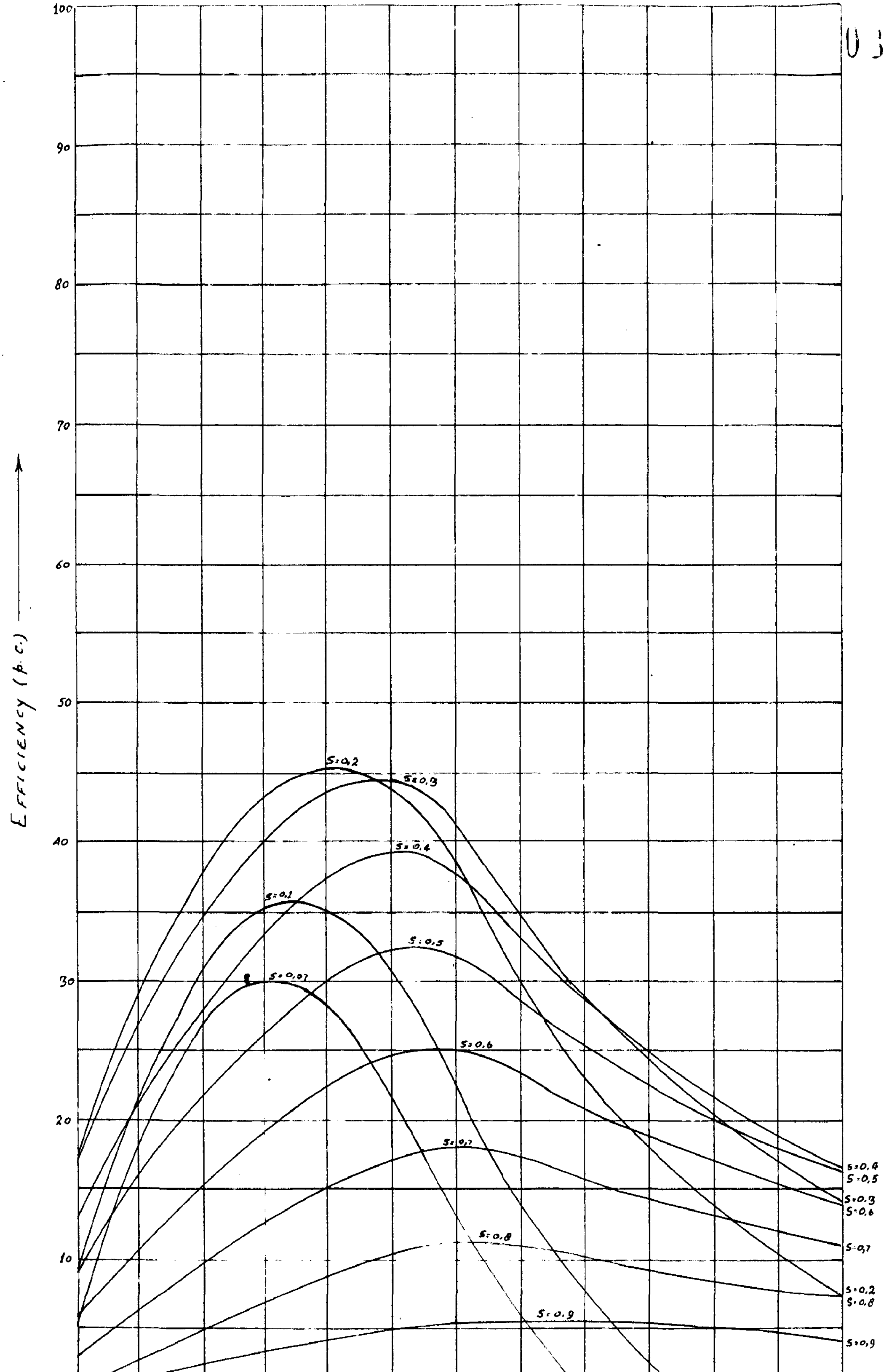
Calculation of efficiencies at Various slips & Capacities Contd. (see graph Nos. III.

S	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
P_o	-0,0648	0,2013	0,3095	0,3279	0,3027	0,2508	0,2004	0,1405	0,0858	0,0438	0,000
$P_o - 0{,}0068$	-0,058	0,1945	0,3027	0,3211	0,2959	0,244	0,1936	0,1337	0,079	0,037	0,000
η per cent	-13,8	35,0	45,8	43,8	37,9	29,9	22,4	15,3	8,8	4,1	0,0
C = 15 μF $EI(\frac{b}{2a})^2$	0,2875	0,588	0,773	0,880	0,958	1,008	1,017	1,045	1,052	1,052	1,038
$GL(\frac{c}{2a})^2$	0,492	0,2875	0,1663	0,0941	0,0553	0,0305	0,017	0,011	0,0098	0,0106	0,014
P_i	0,7795	0,8755	0,9393	0,9741	1,0133	1,0385	1,034	1,056	1,0618	1,0626	1,0523
$P_i + 0{,}07$	0,8495	0,9455	1,0093	1,0441	1,0833	1,1085	1,104	1,126	1,1318	1,1326	1,1223
$EJ(\frac{b}{2a})^2$	0,000	0,3135	0,428	0,438	0,408	0,347	0,270	0,1995	0,1262	0,0663	0,000
$-GP(\frac{c}{2a})^2$	-0,2085	-0,1122	-0,0593	-0,0304	-0,0157	-0,0074	-0,0035	-0,0017	-0,0011	-0,0006	0,000
P_o	-0,2085	0,2013	0,3687	0,4076	0,3923	0,3396	0,2665	0,1978	0,1251	0,0657	0,000
$P_o - 0{,}0068$	-0,2017	0,1945	0,3619	0,4008	0,3855	0,3328	0,2597	0,191	0,1183	0,0589	0,000
η per cent	-25,9	22,2	38,5	41,1	38,0	32,0	25,1	18,1	11,1	5,5	0,0
C = 20 μF $EI(\frac{b}{2a})^2$	0,319	0,651	0,856	0,993	1,082	1,133	1,210	1,238	1,258	1,264	1,275
$GL(\frac{c}{2a})^2$	0,940	0,629	0,435	0,306	0,2245	0,1616	0,1193	0,0867	0,0636	0,0465	0,033
P_i	1,259	1,280	1,291	1,299	1,3065	1,2946	1,3293	1,3247	1,3216	1,3105	1,3085
$P_i + 0{,}07$	1,329	1,350	1,361	1,369	1,3765	1,3646	1,3993	1,3947	1,3916	1,3805	1,3785
$EJ(\frac{b}{2a})^2$	0,000	0,347	0,473	0,494	0,462	0,390	0,321	0,2365	0,1509	0,0797	0,000
$-GP(\frac{c}{2a})^2$	-0,398	-0,245	-0,1553	-0,0987	-0,0636	-0,0394	-0,0244	-0,0138	-0,007	-0,0027	0,000
P_o	-0,398	0,102	0,3177	0,3953	0,3984	0,3506	0,2966	0,2227	0,1502	0,077	0,000
$P_o - 0{,}0068$	-0,4048	0,0952	0,3109	0,3885	0,3916	0,3438	0,2898	0,2159	0,1434	0,0702	0,000
η per cent	30,5	7,1	22,8	28,4	28,5	25,2	20,7	15,5	10,3	5,1	0,0
C = 25 μF $EI(\frac{b}{2a})^2$	0,2825	0,600	0,813	0,968	1,078	1,128	1,220	1,292	1,327	1,355	1,372
$GL(\frac{c}{2a})^2$	1,177	0,863	0,656	0,508	0,4075	0,317	0,2575	0,2085	0,170	0,140	0,1128
P_i	1,4595	1,463	1,469	1,476	1,4855	1,445	1,4775	1,5005	1,497	1,495	1,4848

TABLE III Contd.

Calculation of efficiencies at various slips & capacities contd. (see graph Nos. III

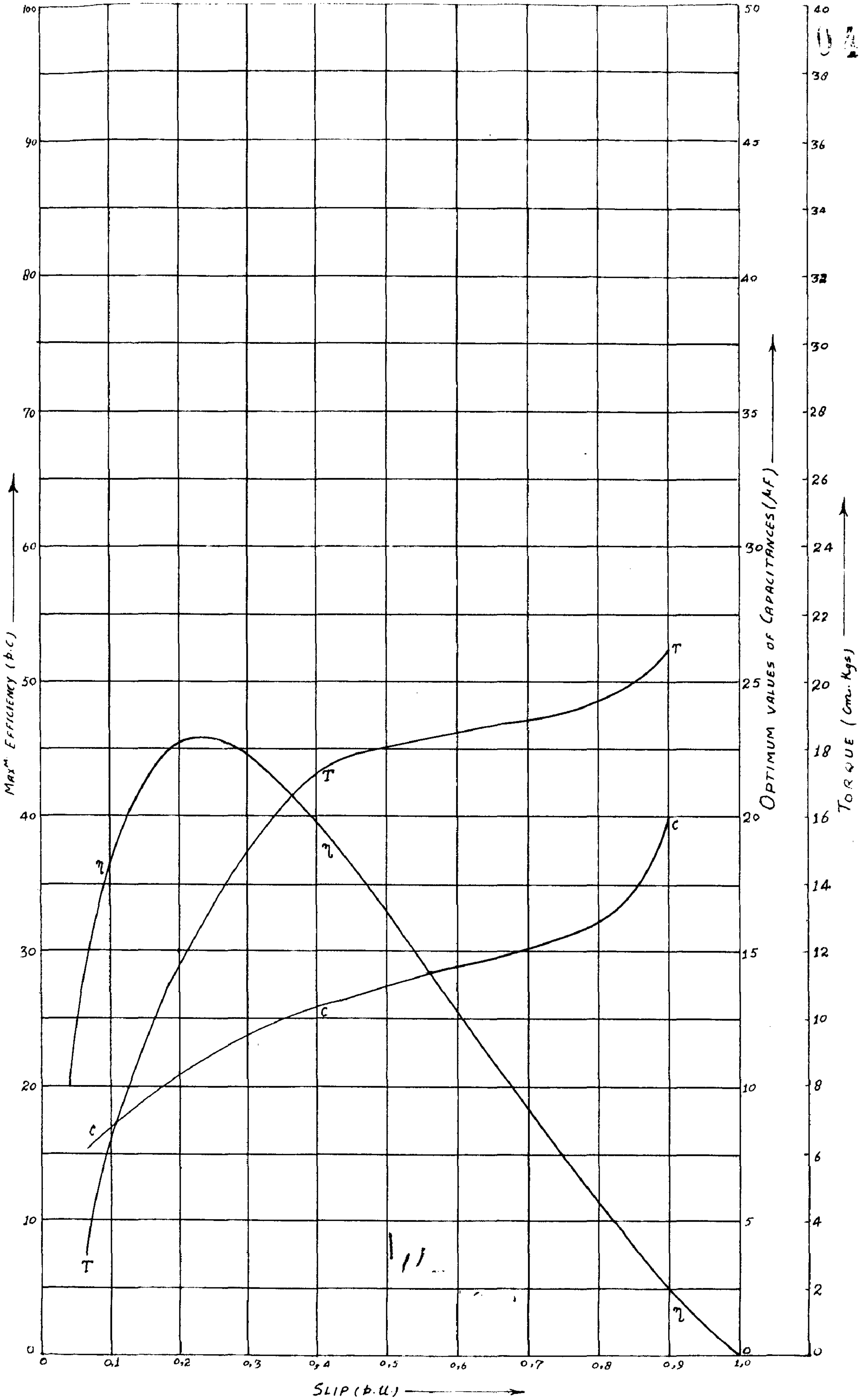
S	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
$P_i + 0,07$	1,5295	1,533	1,539	1,546	1,5555	1,515	1,5475	1,5705	1,567	1,565	1,554
$EJ(\frac{b}{2a})^2$	0,000	0,320	0,450	0,482	0,460	0,388	0,324	0,2466	0,1591	0,0854	0,00
$-GP(\frac{c}{2a})^2$	-0,498	-0,3366	-0,234	-0,164	-0,1153	-0,0773	-0,0526	-0,0331	-0,0186	-0,008	0,000
P_o	-0,498	-0,0166	0,216	0,318	0,3447	0,3107	0,2714	0,2135	0,1405	0,0874	0,000
$P_o - 0,0068$	-0,5048	-0,0234	-0,2092	0,3112	0,3379	0,3039	0,2646	0,2067	0,1337	0,0806	0,000
η per cent	-33,0	-1,5	13,6	20,1	21,7	20,0	17,1	13,2	8.5	5,1	0,00
C: 30 μF $EI(\frac{b}{2a})^2$	0,2365	0,523	0,73	0,894	1,007	1,103	1,178	1,265	1,316	1,350	1,391
$GL(\frac{c}{2a})^2$	1,249	0,993	0,795	0,654	0,547	0,457	0,3905	0,332	0,283	0,2445	0,210
P_i	1,4855	1,516	1,525	1,548	1,554	1,560	1,5685	1,597	1,599	1,5945	1,601
$P_i + 0,07$	1,5555	1,586	1,595	1,618	1,624	1,630	1,6385	1,667	1,669	1,6645	1,671
$EJ(\frac{b}{2a})^2$	0,000	0,279	0,403	0,444	0,430	0,380	0,3125	0,2415	0,1579	0,085	0,000
$-GP(\frac{c}{2a})^2$	-0,528	-0,3875	-0,2835	-0,2108	-0,1549	-0,1115	-0,0798	-0,0527	-0,031	-0,014	0,000
P_o	-0,528	-0,1085	0,1195	0,2332	0,2751	0,2685	0,2327	0,1888	0,1269	0,071	0,000
$P_o - 0,0068$	-0,5348	-0,1153	0,1127	0,2264	0,2683	0,2617	0,2259	0,182	0,1201	0,0642	0,000
η per cent	-34,3	-7,3	7,1	14,0	16,5	16,1	13,8	10,9	7,2	3,9	0,0
$S = 0.07$	$EI = 0,24$; $EJ = 0,128$; $GL = 1,598$; $-GP = 0,633$.										
C μF	0,0	5,0	10,0	15,0	20,0	25,0	30,0				
$(\frac{b}{2a})^2$	0,567	0,907	1,440	2,070	2,280	2,060	1,780				
$(\frac{c}{2a})^2$	0,079	0,314	0,053	0,213	0,446	0,587	0,653				
$EI(\frac{b}{2a})^2$	0,136	0,218	0,346	0,496	0,547	0,496	0,427				
$EJ(\frac{b}{2a})^2$	0,074	0,118	0,184	0,264	0,292	0,269	0,228				
$GL(c/2a)^2$	0,126	0,050	0,0845	0,341	0,713	0,940	1,045				
$-GP(\frac{c}{2a})^2$	-0,050	-0,020	-0,0335	-0,137	-0,282	-0,372	-0,414				
P_i	0,262	0,268	0,4305	0,837	1,260	1,436	1,472				
$P_i + 0,07$	0,332	0,338	0,5005	0,907	1,330	1,506	1,542				
P_o	0,024 ~~0,098~~	0,098 ~~0,1505~~	0,1505 ~~0,127~~	0,127 ~~0,010~~	0,010 ~~-0,108~~	-0,108	-0,186				
$P_o - 0,0068$	0,0172	0,0912	0,1437	0,1202	0,0032	-0,1148	-0,1928				
η per cent	5,2	27,0	28,7	13,3	0,2	-7,6	-12,5				



GRAPH 3 - Efficiency Vs. Capacitance Curves at Various slips

The graph no. III shows the variation of efficiencies with respect to capacitance for various values of slips and is being drawn from the results of table III. This gives the values of the capacitances at which efficiency is maximum for a particular value of slip. The corresponding values of torque are also determined and are plotted as shown in graph no. IV.

GRAPH NO. IV



GRAPH 4 – Maximum Efficiency Vs. slip Curve & Capacitance required and Torques available at these Efficiencies

5. INFERENCES

For the motor under study, the best performances as to give maximum efficiency and good torque at normal running condition is obtained for the value of capacitors lying between 7 to 12 μF as evident from the torque & efficiency Vs. capacitance characteristics at various slips (Graphs I to III).

During starting, capacitor value ranges from 17 to 24 μF giving high starting torque and best values of efficiencies.

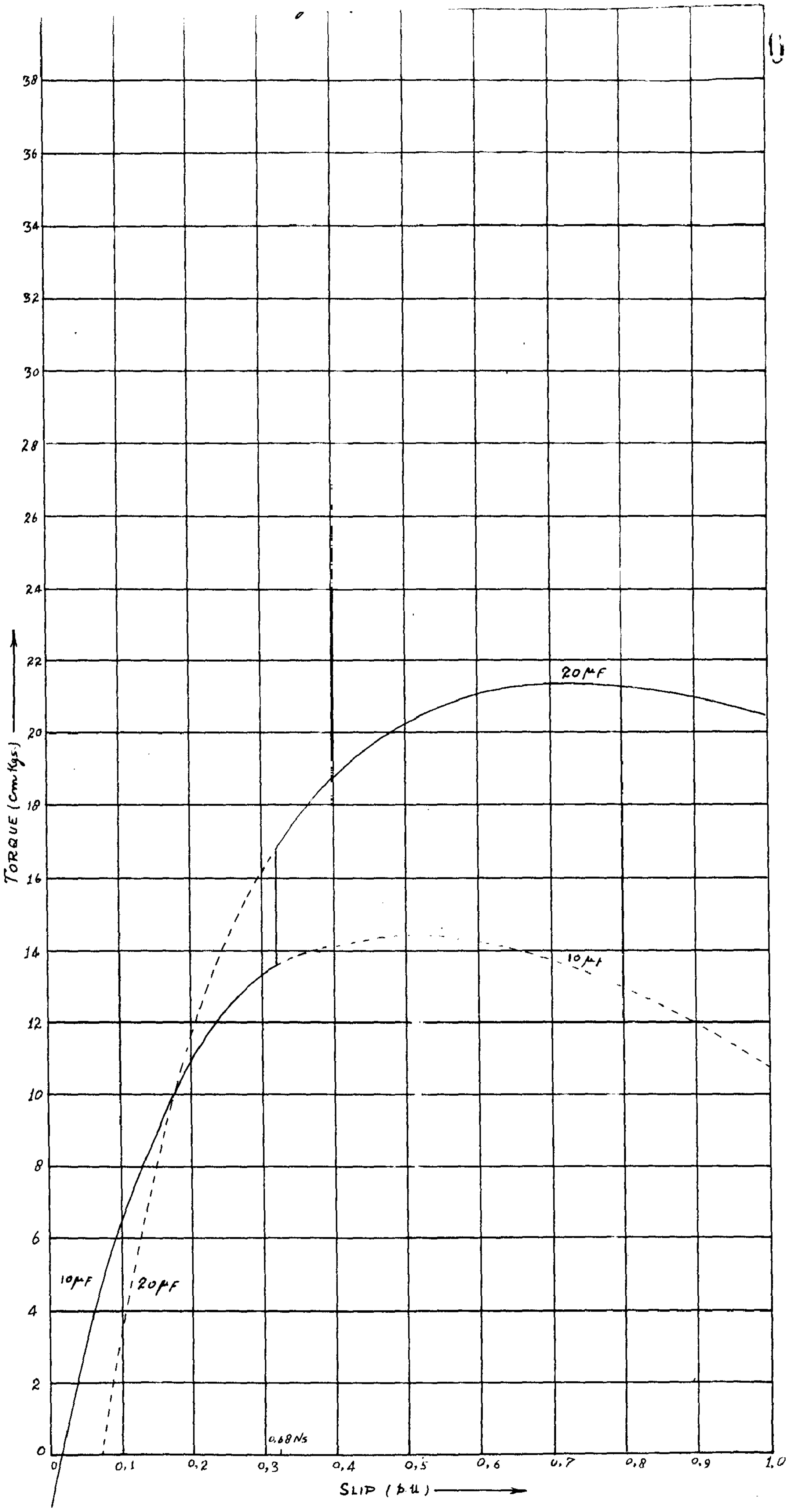
Thus taking a mean value of 10 μF for running condition & 20 μF during starting, good performances can be achieved.

Therefore, two capacitors each of 10 μF, one electrolytic type and the other oil immersed paper condenser were used for starting and the former one was cut out by a centrifugal switch at 68% of Syn. speed. The corresponding results leading to performance determination have been tabulated in table no. IV and are being shown graphically in Figs. V to X.

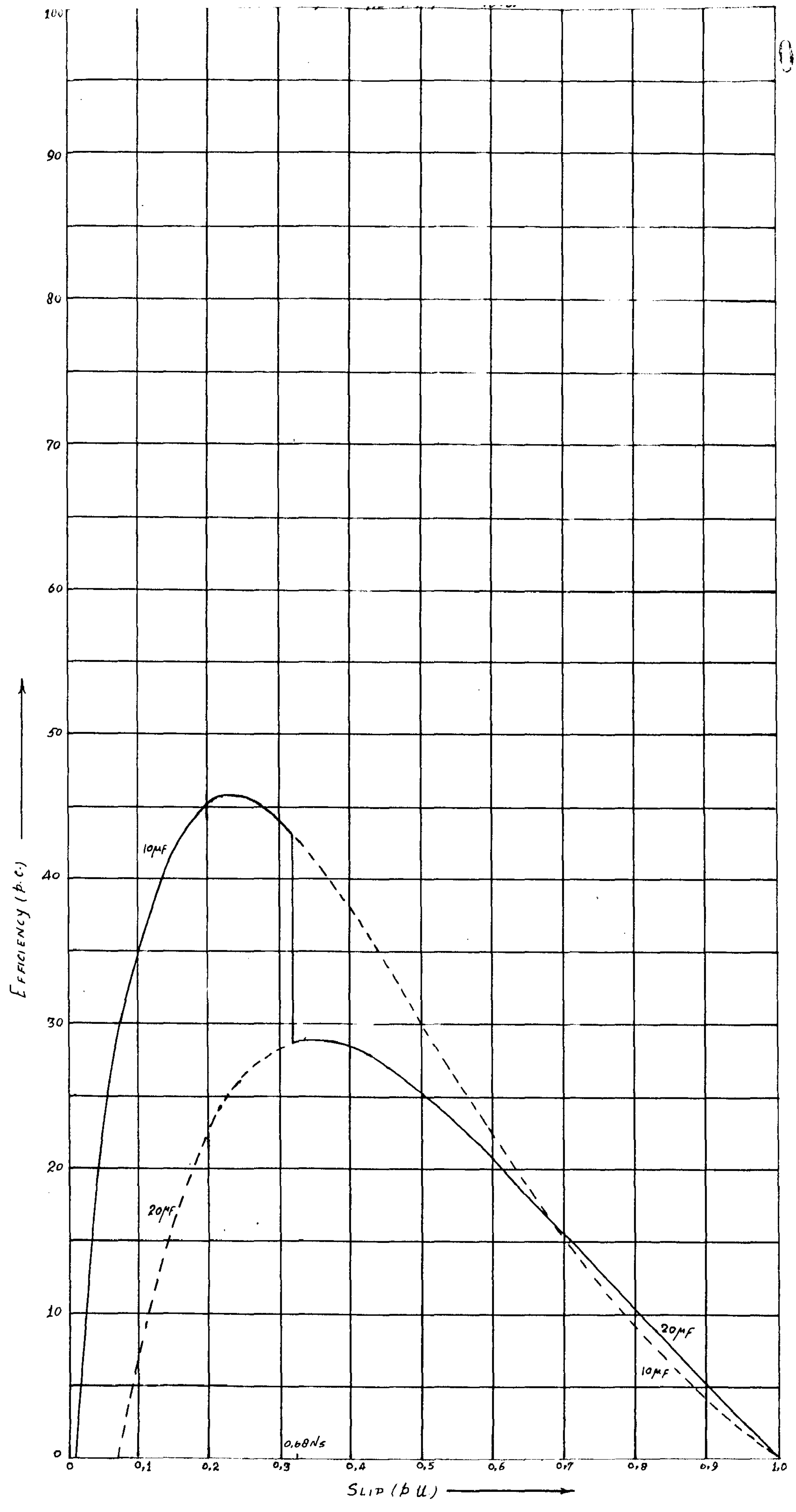
TABLE IV

Calculation of losses, in-put, out-put & condenser voltage at 10µF for running & 20µF for starting period and at various slips.

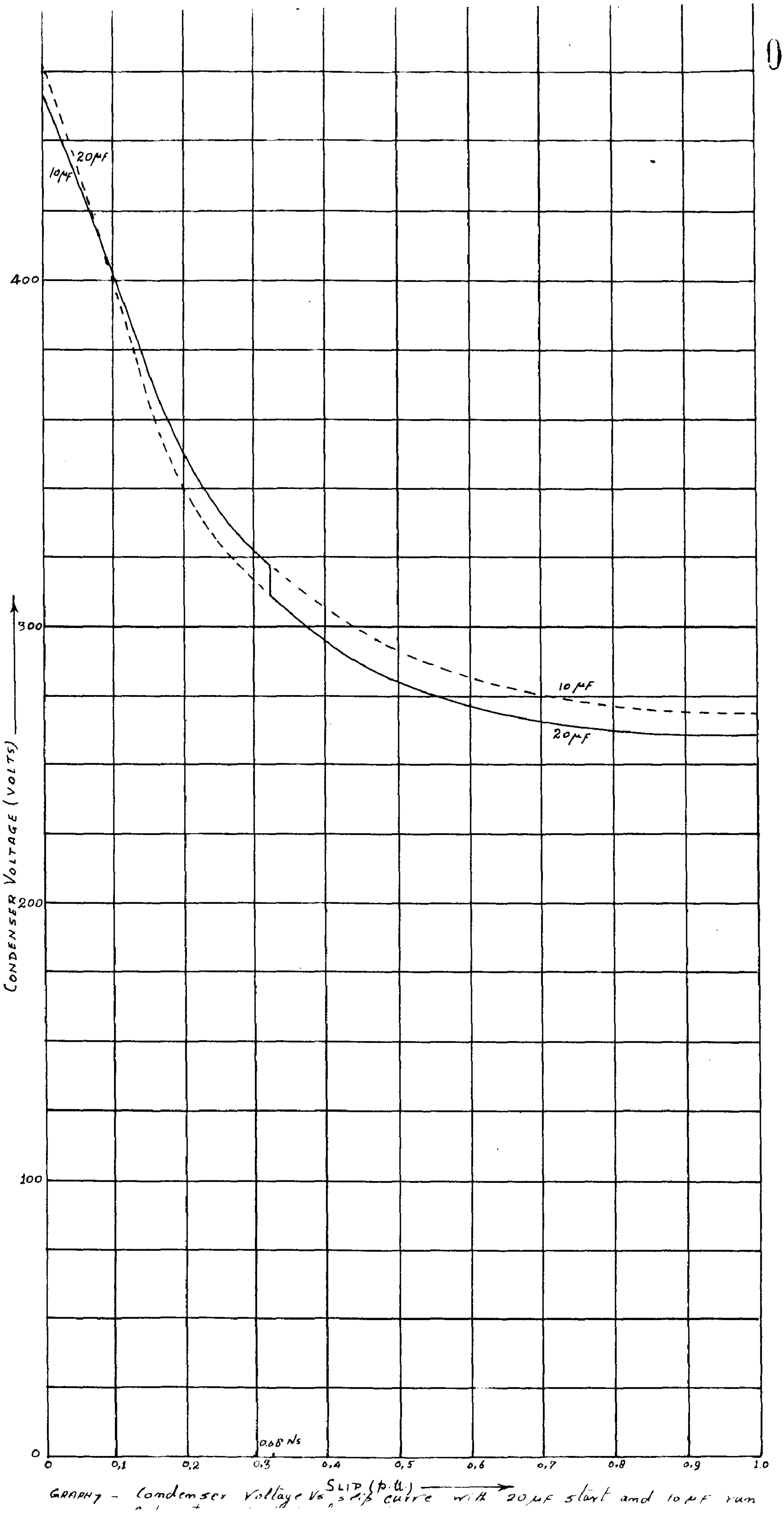
S	0,0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0
$C = 10\mu F$ $P_i - P_o$	0,4133	0,2837	0,2807	0,3338	0,4084	0,4944	0,5919	0,6627	0,729	0,7777	0,8175
$V_{res} = 440(P_i - P_o)$	182,0	124,8	123,6	147,0	180,0	217,5	260,5	291,5	320,5	342,0	359,5
$V_{net} = V_{res} + 33{,}7$ Watts	215,7	158,5	157,3	180,7	213,7	251,2	294,2	325,2	354,2	357,7	390,2
P_i Net = $440(P_i + 0{,}07)$ Watts	184,3	244,5	290,5	322,0	343,5	358,5	379,5	384,5	389,3	392,5	390,5
H_o Net = $0{,}59(P_o - 0{,}0068)$ H.P	-0,0342	0,1148	0,1787	0,1895	0,1746	0,144	0,1142	0,0788	0,0466	0,0218	0,000
a	0,936	0,992	1,052	1,115	1,162	1,212	1,245	1,270	1,290	1,303	1,314
$\frac{\lvert D\rvert}{a}$	2,120	1,832	1,618	1,482	1,395	1,315	1,278	1,253	1,230	1,222	1,221
$U_c = 220\frac{\lvert D\rvert}{a}$ Volts	466,5	403,0	356,0	326,0	306,8	289,4	281,0	275,8	270,5	268,8	268,6
$C = 20\mu F$ $P_i - P_o$	1,657	1,178	0,9733	0,9037	0,9081	0,944	1,0327	1,102	1,1714	1,2335	1,3085
$V_{res} = 440(P_i - P_o)$ $V_{Net} = V_{res} + 33{,}7$ Watts	728,0	518,0	428,0	397,5	399,5	415,5	455,7	485,0	516,0	543,0	575,5
P_i Net = $440(P_i + 0{,}07)$ Watts	761,7	551,7	461,7	431,2	433,2	449,2	489,4	518,7	549,7	576,7	606,2
H_o Net = $0{,}59(P_o - 0{,}0068)$ H.P	584,0 -0,2385	594,0 0,0562	599,0 0,1834	602,0 0,2293	606,0 0,231	600,5 0,2028	615,0 0,171	613,5 0,1273	612,5 0,0846	607,5 0,0414	606,0 0,000
a	0,918	1,007	1,087	1,155	1,205	1,257	1,287	1,310	1,330	1,347	1,356
$\frac{\lvert D\rvert}{a}$	2,16	1,815	1,568	1,430	1,345	1,267	1,238	1,216	1,193	1,184	1,183
$U_c = 220\frac{\lvert D\rvert}{a}$ Volts	476,0	399,5	344,5	314,5	296,0	278,5	272,0	267,5	262,7	260,7	260,5



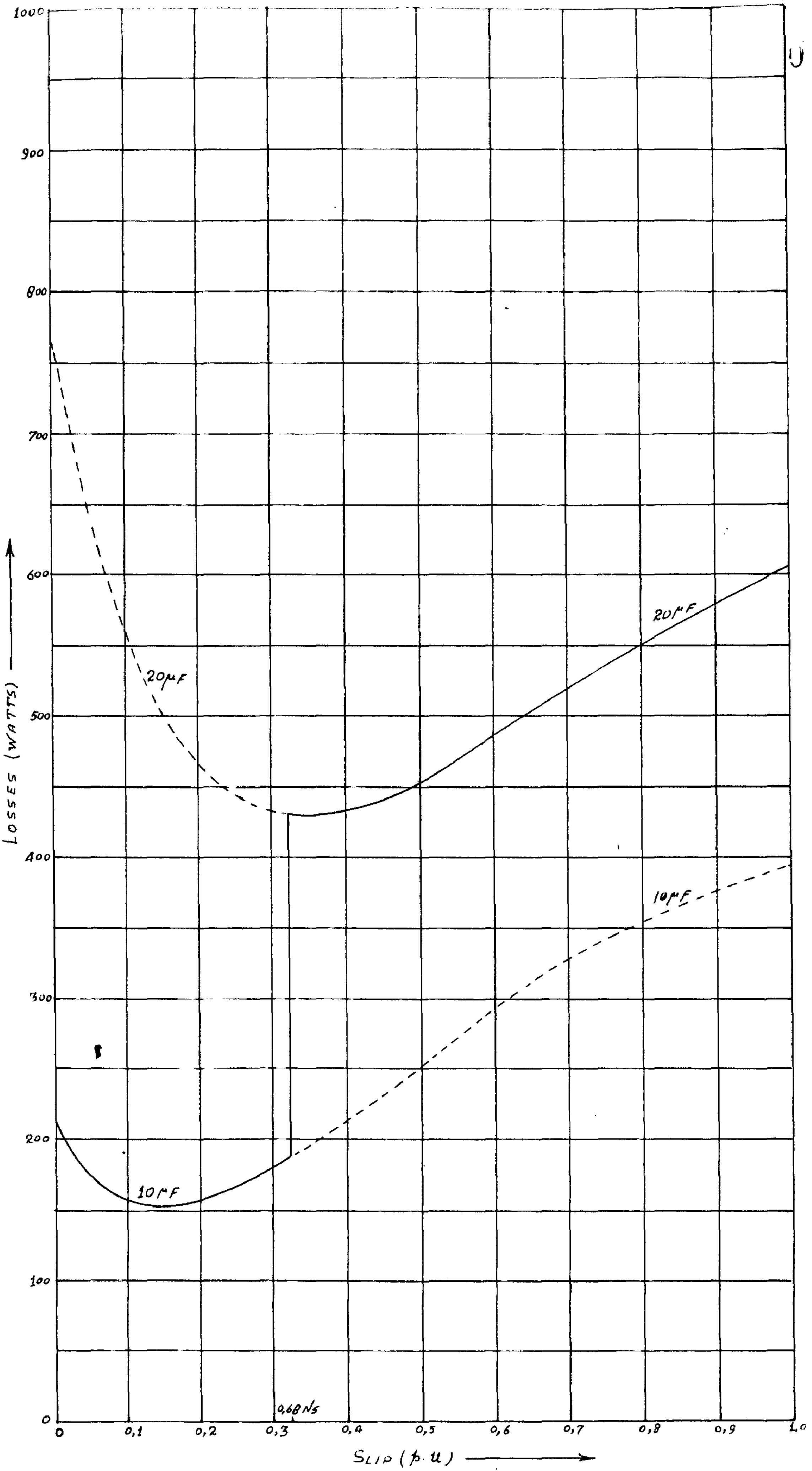
GRAPH 5 - Torque Vs. slip characteristic with 20µF start & 10µF run Capacitors. Centrifugal switch operates at 68% syn speed.



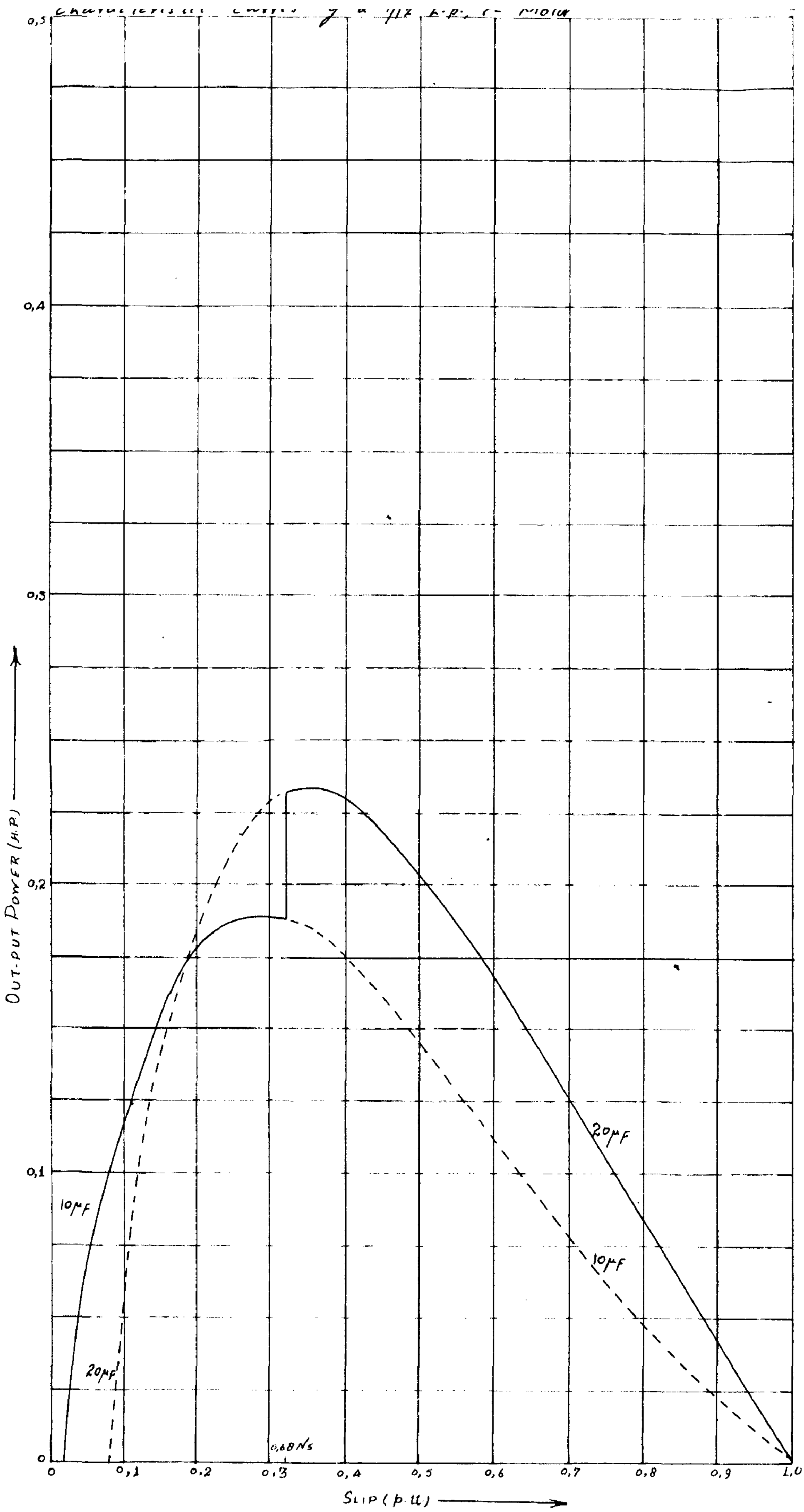
GRAPH 6 - Efficiency Vs. Slip characteristic with 20μF start and 10μF run capacitors. Centrifugal switch operates at 68% syn. speed.



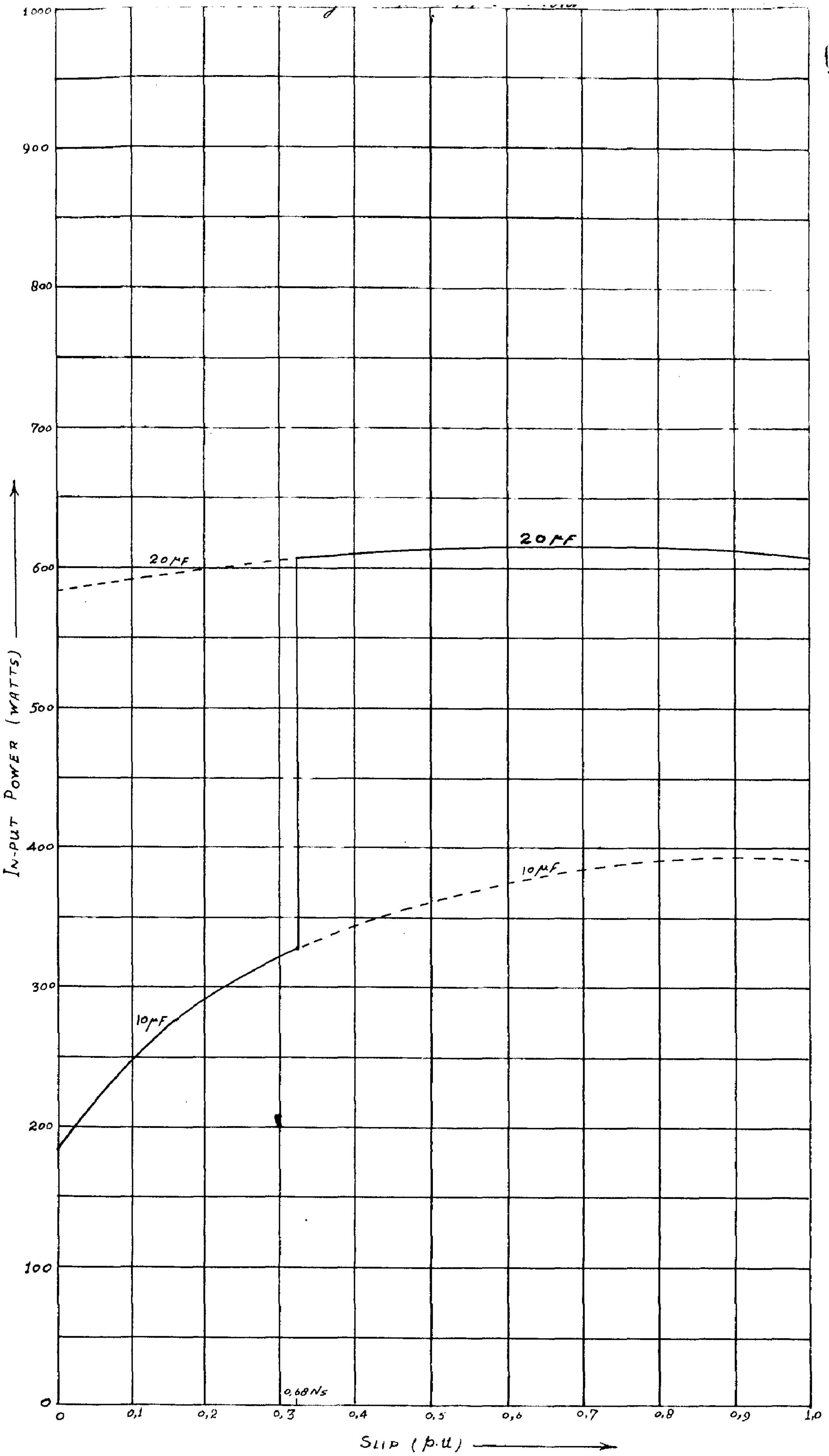
GRAPH 7 – Condenser Voltage Vs slip curve with 20 μF start and 10 μF run



GRAPH 8. losses Vs slip characteristic with 20μF start & 10μF run capacitors. Centrifugal switch operates at 68% syn speed



GRAPH 9 - Output Power Vs. slip curve with 20μF start & 10μF run Capacitors. Centrifugal switch operates at 68% sym. speed.



GRAPH 10 - Input Power Vs. slip curve with 20μF start & 10μF run Capacitors. Centrifugal switch operates at 68%

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