MOD.x040 & MOD.x040-4
MOD.x041 & MOD.x041-4

THREE-PHASE SQUIRREL CAGE INDUCTION MOTOR

(X MEANS THAT THIS MANUAL IS VALID FOR ALL MODELS 0.1.2.3.4.5.6.7.8.9)

INSTRUCTION MANUAL

CE

COMPANY
WITH QUALITY SYSTEM
CERTIFIED BY DNV
=ISO 9001/2000=

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ENX040MN	Rev.1-2003	Made in Italy

ASSIGNMENTS LIST

Presentation and operation test

BASIC ASSIGNMENTS

1. **Machine examination**
2. **Star connection**
3. **Delta connection**
4. **Revolution sense and inversion of rotation**
5. **Measurement of the stator winding resistance.**

ADVANCED ASSIGNMENTS

6. **No-load test and separation of mechanical losses from iron losses and from various origins losses, by using the extrapolation method.**
7. **Short circuit characteristic**
8. **Plotting the circle diagram.**
9. **Plotting the mechanical characteristic.**
10. **Determination of the conventional efficiency**

MACHINE PRESENTATION

THREE-PHASE SQUIRREL CAGE INDUCTION MOTOR

Technical characteristics: See the label on the machine and report significative data below

Power: kW	Speed:__________ rpm	
Voltage ______/_______V STAR / DELTA	Current: ______/_____A STAR / DELTA	Power factor:_____

TERMINAL BOARD CONNECTIONS

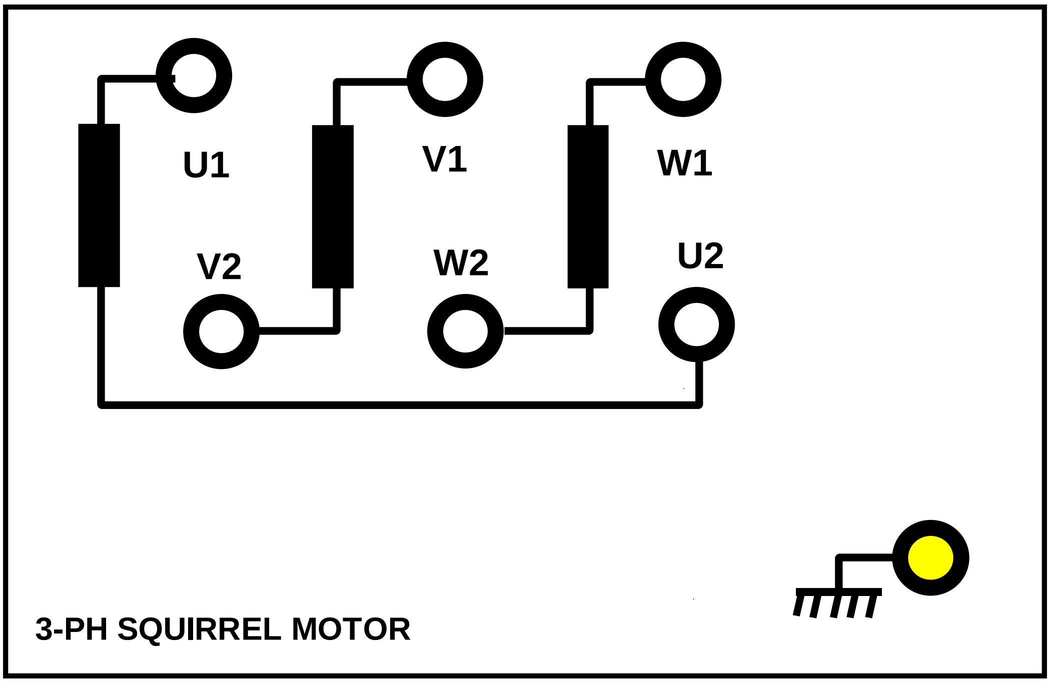

Fig 1

U1-U2; V1-V2; W1-W2 STATOR WINDINGS

RECOMMENDATION FOR SAFE AND EFFICIENT OPERATION

Owing to the versatility and characteristics of this electrical machine training aid, the following measures must be adhered to:

CAUTION

HIGH VOLTAGE

HANDLE THE EQUIPMENT WITH EXTREME CARE AS HIGH VOLTAGES ARE PRESENT AT SOME SOCKETS AND EXPOSED TERMINAL

1) The supply to the machines must be protected by earth leakage;

2) All connections must be terminated correctly at both ends before power is connected.

3) No exposed conductive parts of connection must be visible after the connection.

4) No connections must be disconnected whilst power is still connected.

5) Brushes must not be observed or adjusted whilst power is still connected.

6) Coupling must be done before power is connected.

7) Instructions specified in individual assignments must be adhered to.

8) Further experiments or variation must be done only after the teacher consent.

NOMENCLATURE

The terms ARMATURE and FIELD are often accepted as synonymous respectively with ROTOR and STATOR so far as they are used with reference to DIRECT CURRENT machines

GENERAL

The asynchronous motor is the most used one.

It is also known as rotating field motor, and it doesn't keep its speed rigorously constant, but it allows very little variations of the speed in comparison with the synchronous one in the range of one to eight percent.

If the stator winding is subdivided only in three phase coils , the rotating field makes a complete turn for each period and the motor is called a two pole type one.

If either the winding is subdivided in three contiguous triplets along the stator periphery, the magnetic field makes one half of a turn for each period, and the motor is called a four pole type one.

So you can have either six, eight, ten or twelve pole motors.

Inside the stator you can find the rotor, which is the rotating part one, along the same rotation axis as that of the stator.

In this motor the rotor winding is of the SHORT CIRCUIT type, and is made up by several bars.

This motor has even power enough to start connecting it directly to the main power.

After the motor has inched, the starting rheostat is disconnected.

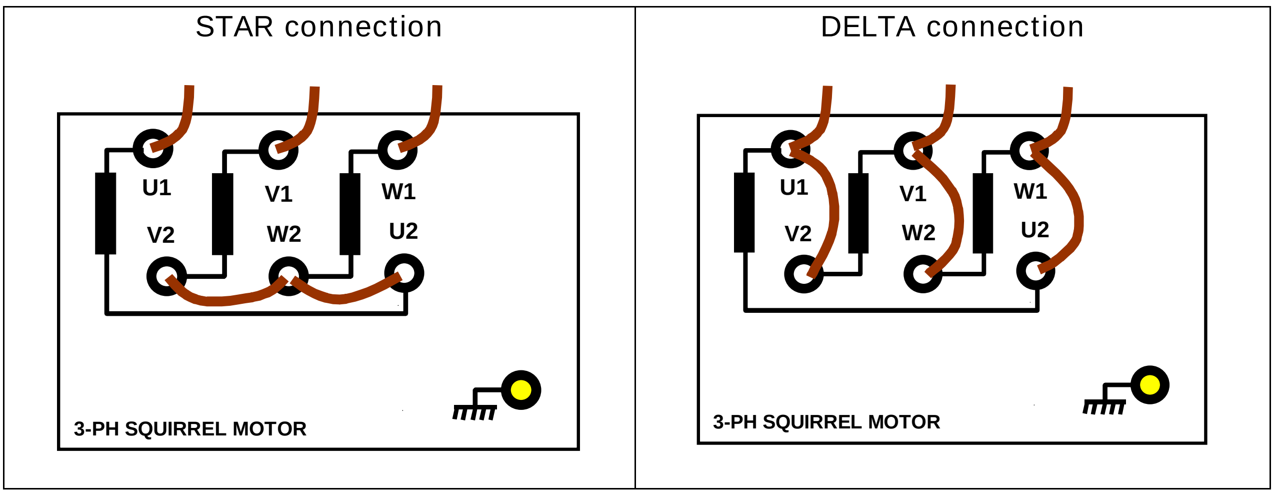

Fig. 2

ASSIGNMENT N.1
MACHINE EXAMINATION

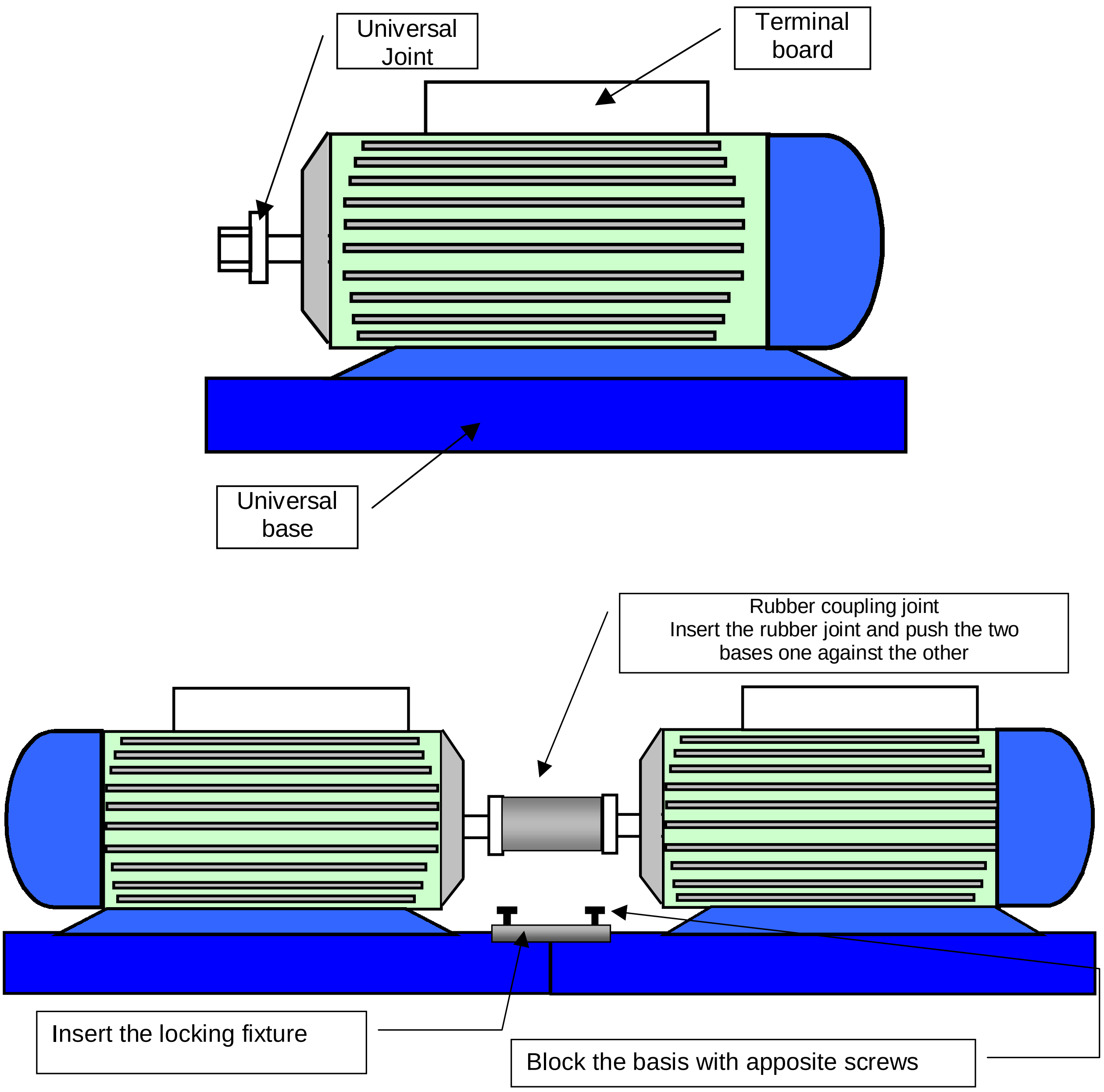

Fig 3

ASSIGNMENT N.2
STAR CONNECTION

The squirrel cage motor is connectable to the three-phase 380V (or 415V) main at star and delta connection.
To verify the operation of the motor realise the connections shown below and switch on directly to the mains.

380V (or 415V) **direct on line**

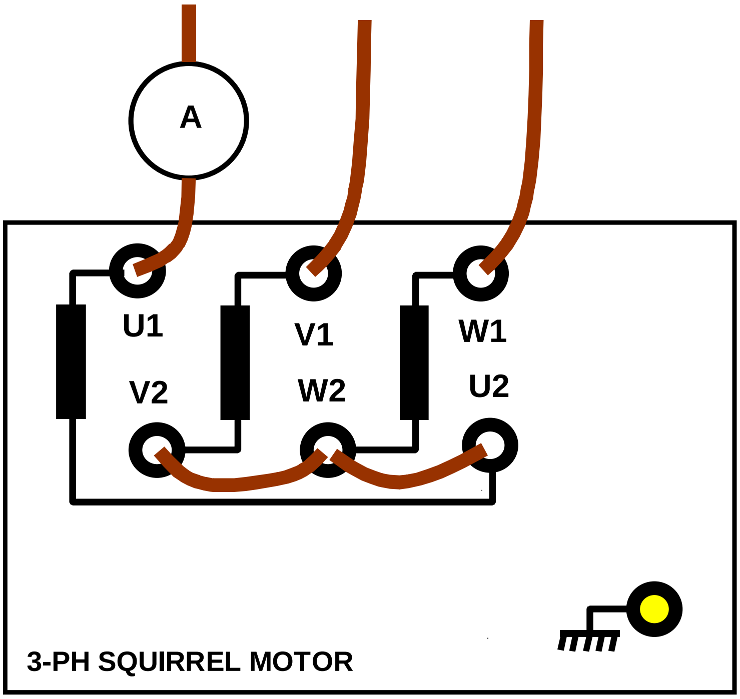

Fig. 4

Using the EMMS power console the operation are the following:
Connect the power supply to the 400V (or 415V) 3-phase main.
Be sure that all knobs are at minimum position (total counter-clock wise)
Connect the motor's phases U1-V1-W1 respectively to R-S-T of power supply.
Connect the earth to the earth of the motor.
Switch on the general switch I1. Switch on the switch I2. Acting on the knob K2 toward max increase the output till to read 400V (or 415V) on V1.

Verify the rotation of the motor; Measure the phase current reading the ammeter A1, A2 and A3; Measure the speed; decrease the knob K2 at min position.
Switch off the circuit breaker I2.

ASSIGNMENT N.3
DELTA CONNECTION

The three-phase squirrel cage asynchronous motor can be connected directly to the 230 400 (or 240-415V) three-phase main.
To verify the operation of the motor realise the connections shown below and switch on directly the 240V three-phase mains.

220V (or 240V) **direct on line**

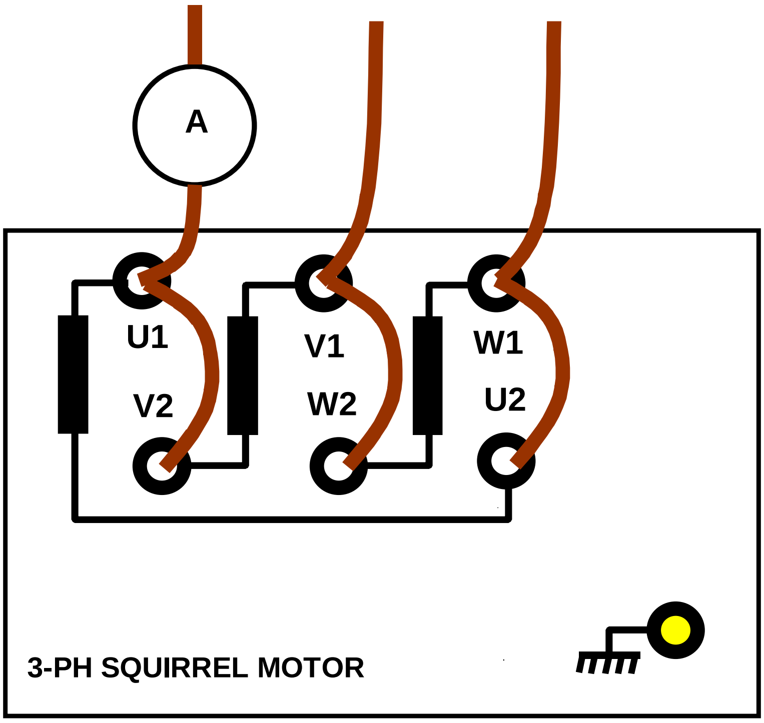

Fig. 5

If 230V 3-phase is not available, you can use the EMMS universal power console to obtain the 230V 3-phase following this procedure.

Connect the power supply to the 380V (or 415V) 3-phase main.
Be sure that all knobs are at minimum position (total counter-clock wise)
Connect the motor's phases U1-V1-W1 respectively to R-S-T of power supply.
Connect the earth to the earth of the motor.
Switch on the general switch I1. Put on the switch I2. Acting on the knob K2 toward max increase the output till to read 230V (or 240V) on V1.
Verify the rotation of the motor; Measure the phase current reading the ammeter A1, A2 and A3; Measure the speed; decrease the knob K2 at min position.
Switch off the circuit breaker I2.

DISCUSSION

Discuss with the teacher the reason because the phase current with star connection is lower than the same current measured with delta connection.

ASSIGNMENT N.4
REVOLUTION SENSE AND INVERSION OF ROTATION

Modify the rotation sense of a motor is very important.
In industrial application inverse a sense of traction of cranes, inverse the direction of a machine tool, without use of expensive gears, reverse the sense of a fan to obtain aspiration or blow is essential.

How is possible to modify the revolution sense of a slip-ring motor?

Exercise 4/1: Realise the following circuit

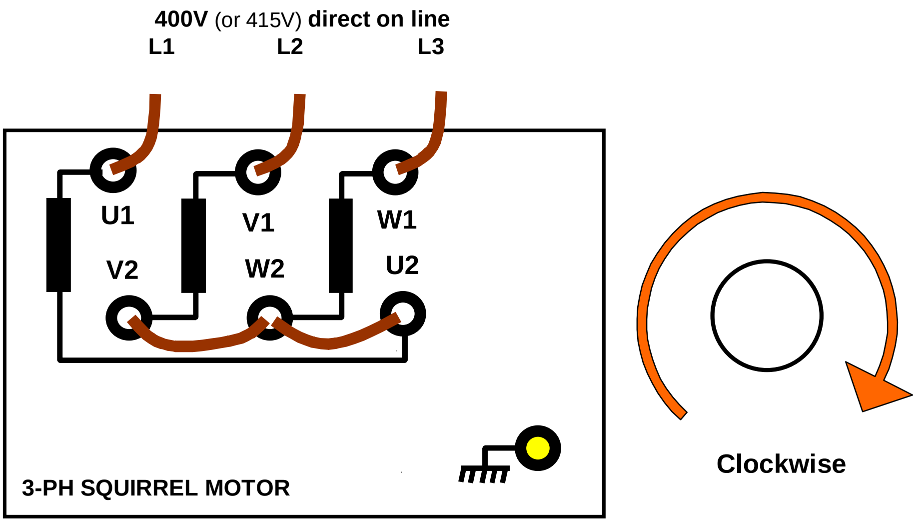

Fig 7

Power the motor and observe the revolution sense.

Exercise 4/2: Now realise the following circuit:

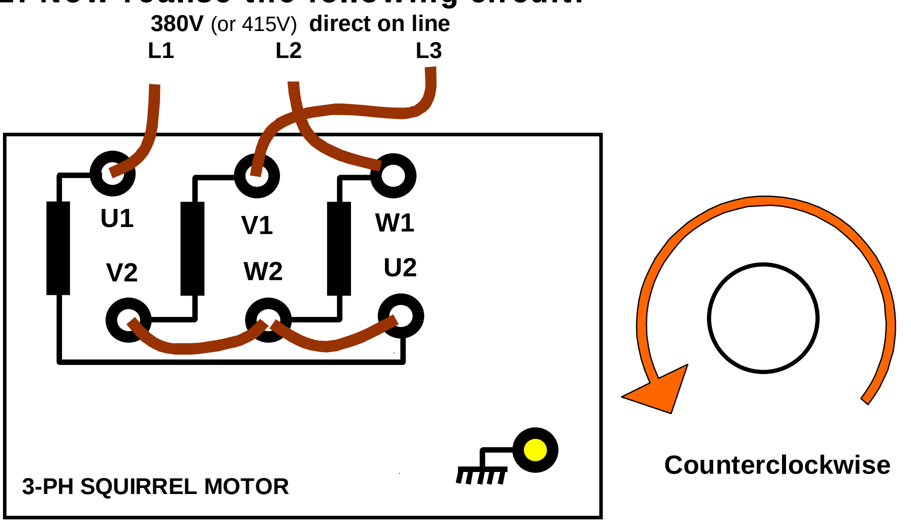

Fig 8

Power the motor and observe the revolution sense

Exercise 4 / 3 realise the following circuit

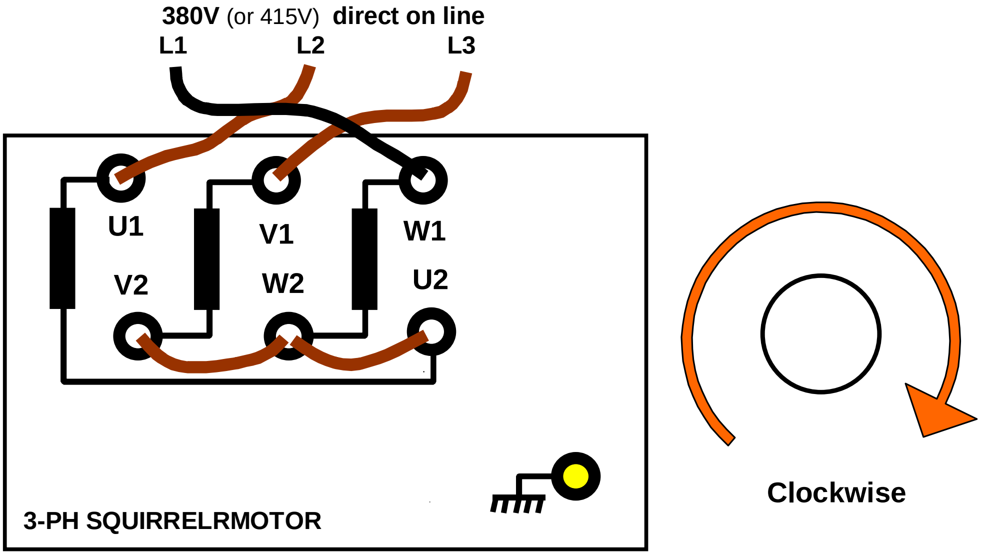

Fig 9

Power the motor and note the revolution sense.

As you have just verified the rotation sense is modified only if a phase is changed.

DISCUSSION

Try to discuss with the teacher why the rotation sense modify if only a phase is changed

Example of start with starting rheostat.

The stator windings can be connected to the starting rheostat in order to restrict the inching current.

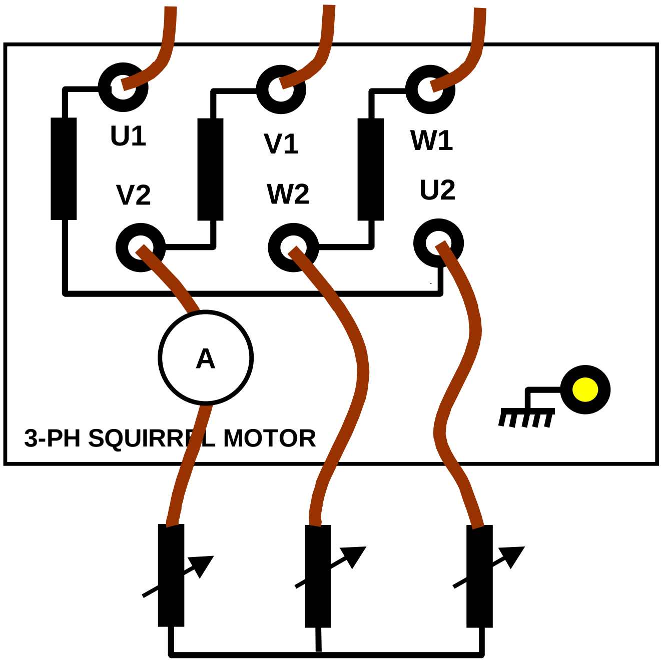

Fig 10
Starting Rheostat

To verify the action of starting rheostat, connect the motor as showed in the above figure and power the motor directly on line 380V (or 415V) with the starting rheostat completely inserted (R MAX)

Read the current measured in the ammeter A.

Decrease gradually the ohmic value (pass at 2/3 position).

Read and note the current measured in the ammeter A and note the speed variation

Decrease again the ohmic value (pass at 1/3) position.

Read and note the current measured in the ammeter A and note the speed variation

Decrease again the ohmic value up to obtain the short circuit of slip ring. This position is the usual condition for operation.

The above procedure is used only for big motors.
In all exercises contained in this manual the motor will start with the rings in short circuit and powered directly to the line.

ASSIGNMENT N.5
MEASUREMENT OF THE STATOR WINDING RESISTANCE

THEORY

If you know the winding resistance value, you can calculate the conventional efficiency, the speed shifting under load and the couple by plotting the circle diagram.

The asynchronous motor has three windings U1-U2, V1-V2 and W1-W2, which are correspondent to the three phases, whose ends are available on the terminal board, as showed in fig. 4.

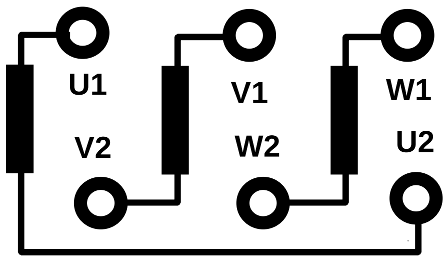

Fig. 11

The stator can be powered at STAR or DELTA connections, as showed in fig. 5.

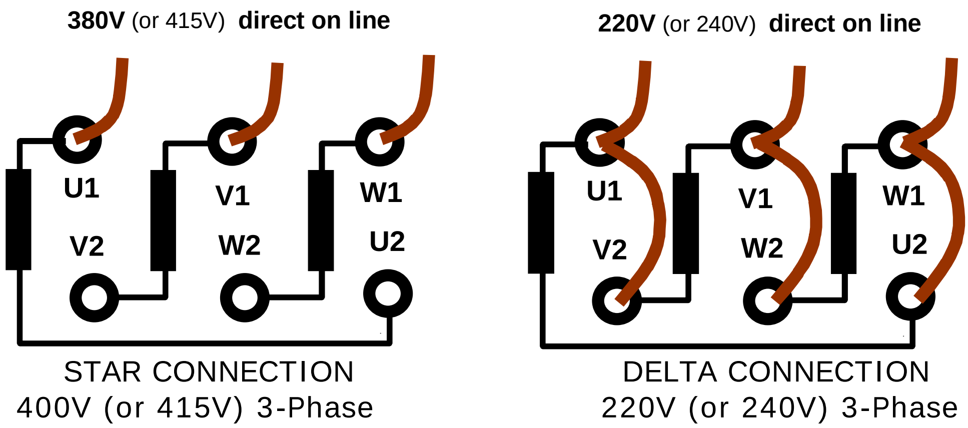

Fig. 12

Delta connection is not advised since some internal currents could form a third harmonic induced f.e.m., being in phase each other.

These harmonic components sometimes are too great because it is difficult to get a correct shape of the pole shoes, which in turn give a sinusoidal waveform air core induction.

If the rated current flows in the stator winding, the stator resistance is low and you must measure it with methods suitable to small resistors.

The measurement is to be carried out in c.c. and some hours after the motor has been still, so that it reaches the ambient temperature.
The three phases must have almost the same ohmic value.

CONNECTION DIAGRAMS

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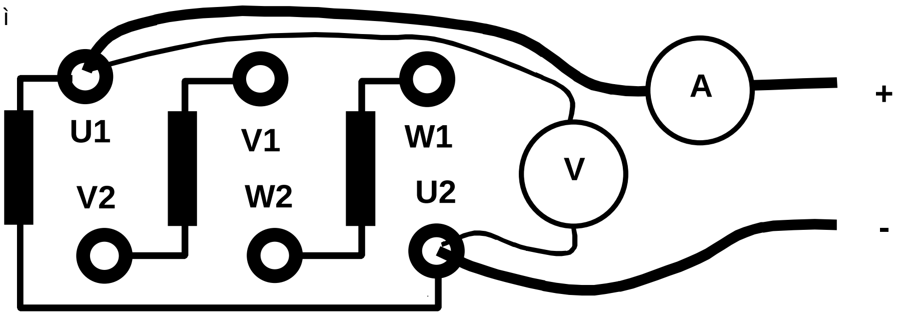

Fig.13

V/A = stator resistance of phase 1.

Measurement of the stator resistance of an asynchronous motor with the volt-ammetric method.

PROCEDURE FOR MEASURING THE STATORIC RESISTANCE

Since you have connected the circuit shown in fig.6, switch on the main power and control that the current in the U1-U2 winding is 0.2A - 0.3A about.

Connect the voltmeter directly across the motor terminals and read the voltage drop and the current.

Repeat the same, connecting in turn V1-V2 and W1-W2.

RESULTS TABLE

Test Temperature: 20°C.

	Ammeter (A)	Voltmeter (V)1	R phase (Ω)	R phase media (Ω)
U1-U2				
V1-V2				
W1-W21				

Fig.14

$$Rphase = \frac{V}{I};$$

$$Rphasemedia = \frac{Rphase1 + Rphase2 + Rphase3}{3}$$

The three values are practically identical.
If you obtain a difference of more than 7% repeat the reading because an error is present.

ASSIGNMENT 6
NO LOAD TEST AND SEPARATION OF MECHANICAL LOSSES FROM IRON LOSSES AND FROM VARIOUS ORIGINS LOSSES, BY USING THE EXTRAPOLATION METHOD

THEORY

The no load test is carried out feeding the motor, and letting it to run freely without any mechanical load.

Running this way at the rated voltage, the motor draws from the mains power enough for overcome the force of inertia and the losses in the iron core by hysteresys and by eddy currents.

Iron losses are frequency related and reside inside the stator, which is crossed by the line frequency voltage. The rotor rotates almost in synchronism with the electric field and is crossed by a nearly constant flux, so eddy currents and magnetic hysteresys losses don't rise inside it.

We should also consider the copper losses calculated in the assignment 1.

This test can be carried out with a single trial, feeding the motor with the rated voltage; however we'll make it in several steps with decreasing voltages, in order to plot the results.

Stator coils may be star or delta connected, as you want.

CONNECTING DIAGRAMS

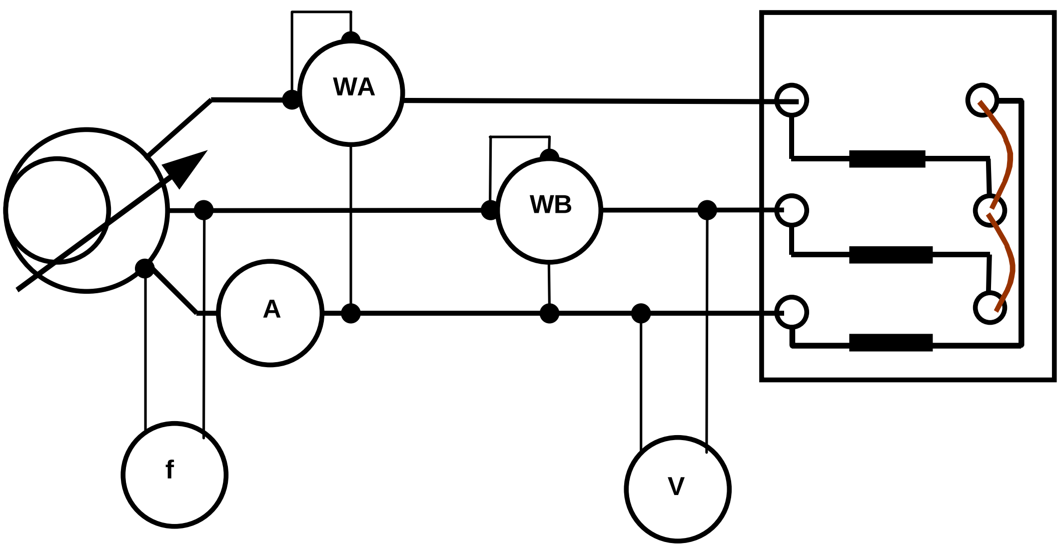

Fig.15

The voltmeters must be connected before the ammeters for reducing the measure errors.

PROCEDURE

When you start the motor, you must take care to short circuit all the ammeters, because the inching current may be up to ten times the rated one.
You can either increase gradually the voltage to the rated one, checking that the ammeters don't go outside the range.

Take your readings decreasing the voltage steps, and precisely:
- voltage V on the V voltmeter;
- no load current on the A ammeter;
- powers on Wa and Wb power meters.

You must repeat the test till the engine reduces its speed, so that the speed offset is no longer negligible.
You'll be able to find this point, when the no load current tends to increase instead of decreasing, as the motor slows down.
If you further decrease the voltage, the motor will stop and the current will get the short circuit value.
The voltage threshold value is the minimum one, and below it the measure is no longer reliable.

RESULT TABLE

F=50Hz; Stator connection DELTA (Δ)

n	V0 V	Adsorbed current W	Adsorbed Power W		P0 W	Cos φ 0	Pm +Pfe W
	240		WA	Wb			
	230						
	220						
	210						
	200						
	190						
	170						
	150						
	130						
	90						

From the power meter readings you must calculate:
- no load absorbed power P_0 = k(WA + WB);
- no load power factor, using the formula:

$$\cos\varphi_0 = \frac{(x+1)}{2\cdot\sqrt{(X^2 - X + 1)}}$$

where x = WB/WA.

$$Pm + PFe = P_0 - 3(Rf)\cdot\left(\frac{I_0}{\sqrt{3}}\right)^2$$

GRAPHS

You can now plot the no load graphs of the current related to the voltage.

$I_0 = f(V)$ graph.

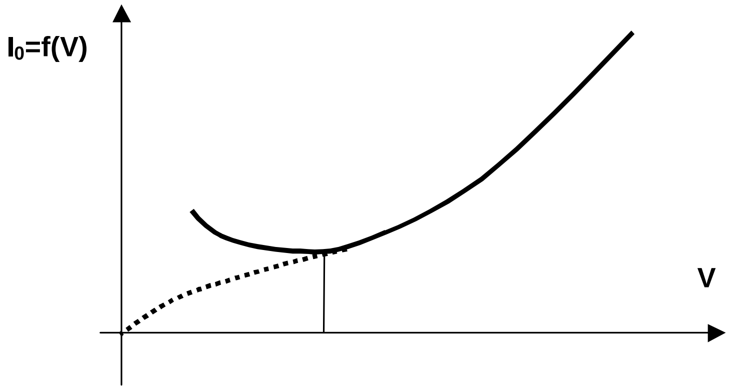

Fig.16

The no load current increases as the voltage increases, at first slowly, and afterwards rapidly and rapidly.

$P_m + P_f = f(V)$ graph.

The power increases with voltage.

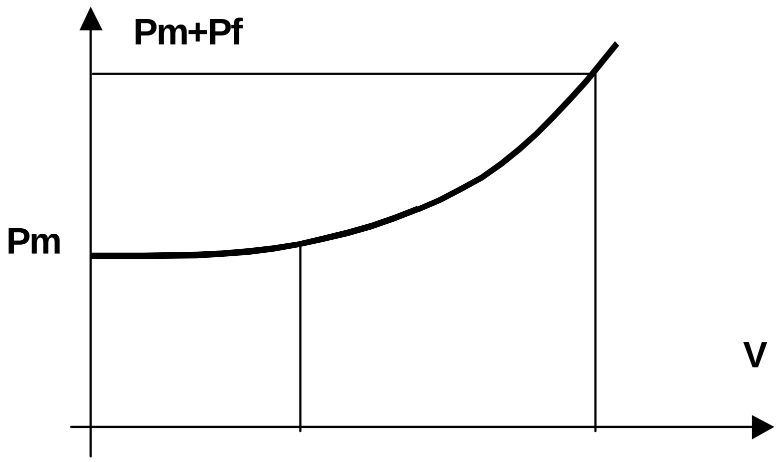

Fig.17

The power is calculated as a sum of two parts, the first one is due to mechanical losses and is constant; the second one varies with the square voltage and shows a parabolic shape.

Power factor cos φ P_0 = f(V) graph.

The no load power factor decreases as voltage increases, because the current magnetising component grows more rapidly than the active losses dependent one.

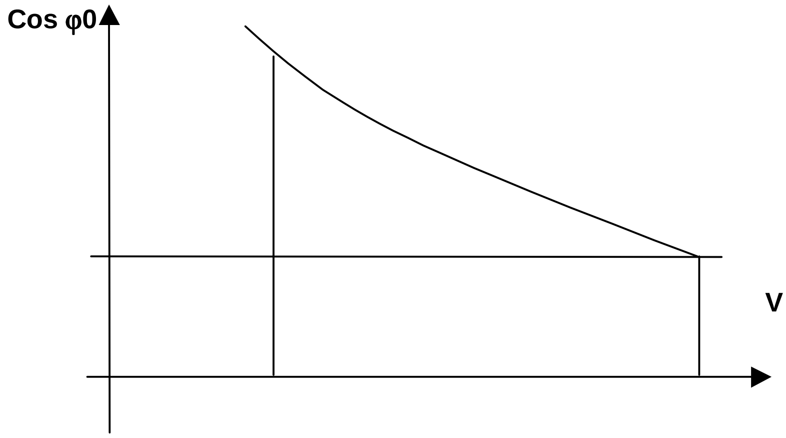

Fig. 18

Characteristic cos φ 0 = f(V) of the no-load power factor of a three-phase asynchronous motor.

SEPARATION OF IRON LOSSES FROM MECHANICAL ONES

The power graph of total losses has almost a parabolic shape because of iron losses.

If we suppose that iron losses are directly proportional to the square voltage, i.e. if:

$$P^{f} = K\ V,$$

we can write:

$$P^{m} + P^{f} = P^{m} + K\ V.$$

If now we put V = 0, we obtain the mechanical losses alone, like in fig. 19

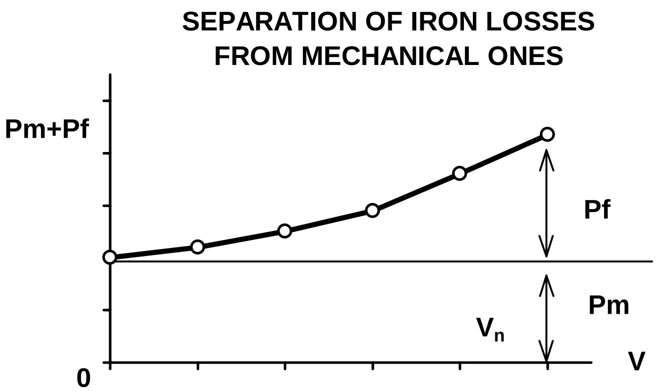

Fig. 19

In practice it isn't possible to attain the null voltage condition and either go below the minimum voltage value which stops the motor.

The null voltage point is to be attained by extrapolating the graph.

ASSIGNMENT N.7
SHORT CIRCUIT CHARACTERISTIC

THEORY

This graph is obtained by keeping the rotor blocked.

So the motor acts like a perfectly balanced load, with a constant impedance and with a small resistance value, which practically equals the equivalent series impedance.

Referring to the equivalent scheme of the engine, which looks like that of a transformer, we see that we can transfer the secondary impedance into the primary, putting it in parallel with the derived equivalent iron impedance, Z_0 as in fig. 20

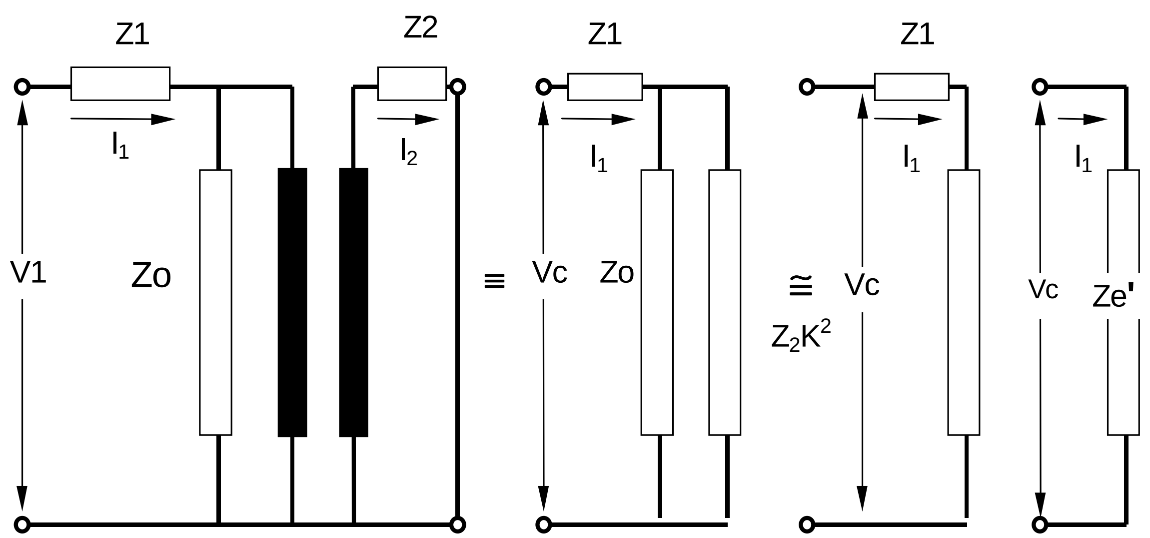

Fig. 20

The series impedance takes usually very small values, while the parallel one has great ones, in a ratio about of 1 to one hundred.

So in a parallel connection we can neglect Z0, and the motor impedance looks like Ze = Z1 + K^2 + Z2.

Therefore the dissipated power under short circuit conditions is almost totally dissipated inside the copper.

By this reason you must make the test at a reduced voltage, so that the engine will not be damaged, and you must stop the trial when the coil current equals the rated one.

CONNECTING DIAGRAMS

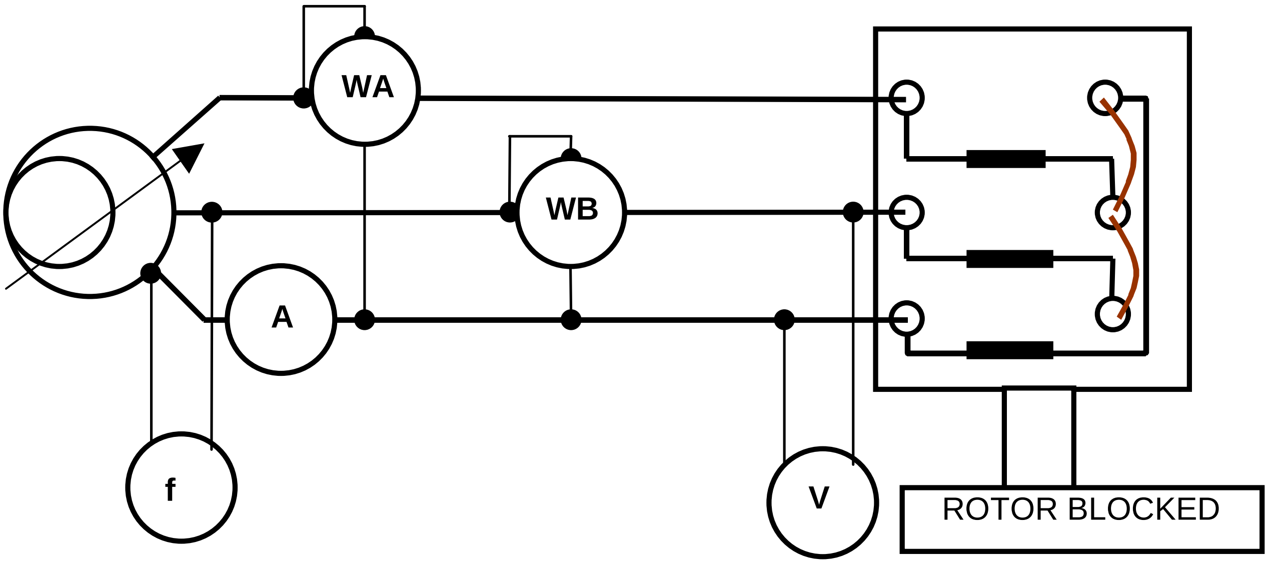

Fig. 21
Short circuit test of an asynchronous motor.

PROCEDURE

Carry on the test in decreasing voltage steps, so that the motor heating is reduced.

Read at the pre-set steps the following values:

- absorbed current I on the A ammeter;
- short circuit voltage V^{cc} on the V voltmeter;
- powers on the A and B power meter.

TABLE OF RESULTS

f = 50Hz; t = 20°C; stator delta connected.

Icc (A)	Volt (V)	Power A (W)	Power B (W)	Pcc (W)	Cos φ

Fig. 22

You can now calculate:

- the power P^{cc} = WA + WB; - the power factor by the relation:

$$\cos \varphi cc = \frac{(X+1)}{2\sqrt{(X^2 - X + 1)}}$$ where X = WA / WB

Calculated and read values let us deduce the equivalent parameters of the machine, the same way as for transformers, i.e.:

- the series impedance $Z_e = V_{cc}/3I$;

- the series equivalent resistance $R_e = Z_e \cdot \cos \varphi\, cc$
- the series equivalent reactance $X^e = Z^e * (\text{sen}\ \varphi\, cc)$

V_{cc} = f(I) GRAPH

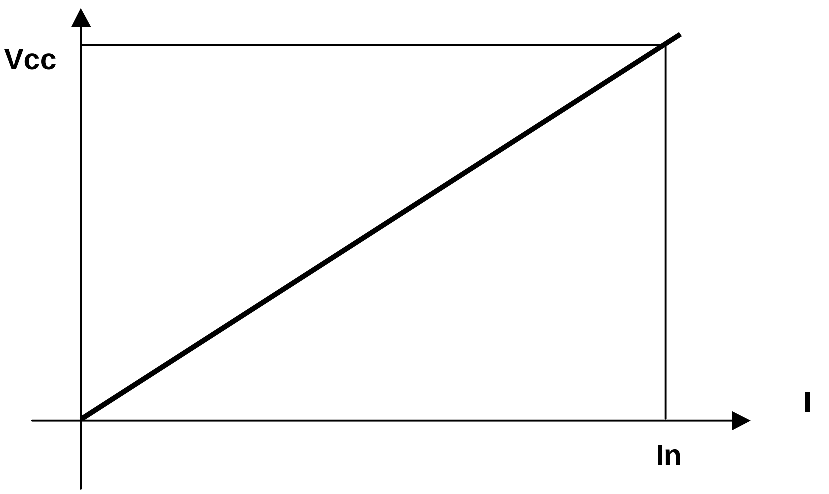

Fig. 23
Short circuit voltage characteristic V_{cc} = f(I) of an asynchronous motor.

ASSIGNMENT N.8
PLOTTING THE CIRCLE DIAGRAM

We'll now relate our results to 75°C.

When temperature varies, the coils resistance varies with a temperature coefficient K_t given by:

$$Kt = 309.5/ 234.5 + t,$$

where t is the environmental temperature.

In the same time the reactance stays constant, therefore we'll find:

$$R(t) = K_t R_e; \quad X_r = X_e;$$

and the new equivalent impedance value we'll be: $Z_r(t) = R(t) + X_e$;

According to these parameters, also the short circuit quantities vary when passing from ambient temperature to 75C, and precisely:

- power $P_{ccr} = R_r * I = 3 K_t R_e * I = K_t P_{cc}$

increases exactly the same way as resistance;

- voltage $V_{cc} = 3 Z_r * I$ varies like the resistance;
- power factor $\cos \varphi = Rr/Zr$

CURRENTS CALCULATION

The circle diagram is drawn according to the condition that all its points refer to the rated voltage.

The no load test gives the I^0 and $\cos f^0$ values for calculating the first point at the rated voltage.

The short circuit test gives a short circuit current at a reduced voltage, so that the machine want be damaged.

If we consider that a blocked engine corresponds to a constant Z^r impedance, the true short circuit current turns out to be:

$$Icc = vN / 3 Zr$$

We can also make a proportional calculation by relating it to 75C.
In fact at the rated current we have:

$V^{cc}(t) = 3\ Z(t)\ In$, while at the rated voltage we have:

$V^{n} = 3\ Z(t)\ I^{cc}$; dividing now member by member we find:

$V^{n} / V^{cc}(t) = I^{cc}/I^{n}$, and $I^{cc} = I^{n} * V^{n} / V^{cc}(t)$;

The short circuit 75C power factor cos $f^{cc}(t)$ has been already calculated.

If you want to draw the circle diagram at an ambient temperature, which you must exactly indicate, you'll omit the calculation at 75C, and you'll only calculate the current at the effective short circuit value, i.e.:

$I^{cc} = V^{n} / \sqrt{3}\ Z^{e}$, or $I^{cc} = I^{n} * V^{n} / V^{cc}$;

DRAWING THE GRAPH

In our orthogonal axes we'll put the voltage as the ordinate and the flux as the abscissa; the current scale is set to 1cm = 1A, as shown in fig. 24

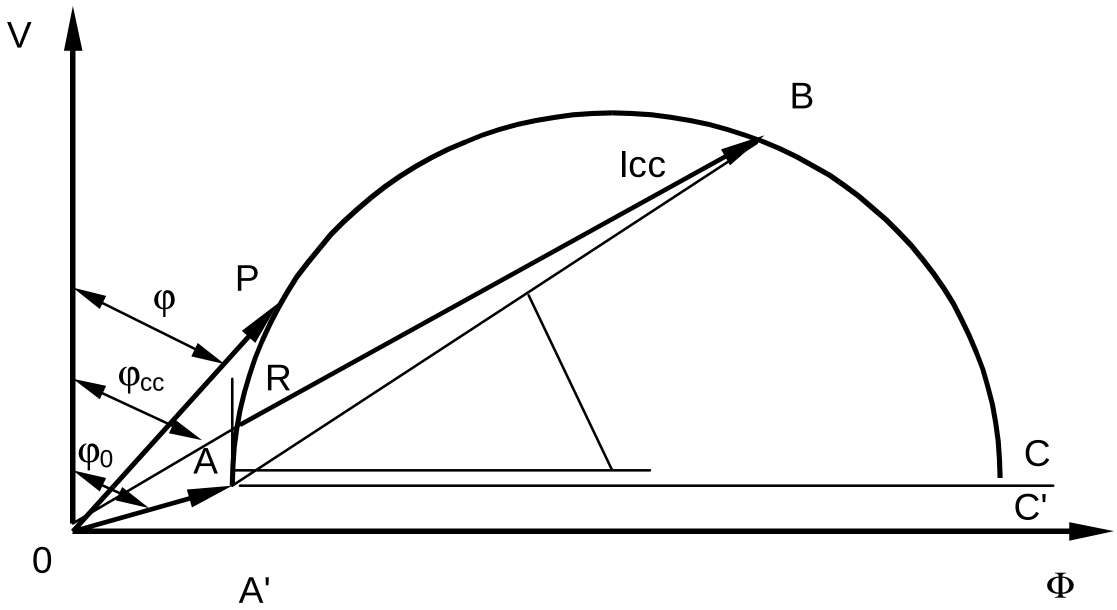

Fig. 24

According to the scale we'll draw the current I^{0} out of phase by an angle^{0} with respect to V, and the current I^{cc} out of phase by an angle cc with respect to V.

I^{cc} and ^{cc} we'll be calculated at 75C or at another temperature, as you want.

Connect points A and B of the currents and draw a vertical segment from A till you meet I^{cc} in R.

The axes of AR and AB segments meet in a point which coincides with the circle centre. An horizontal line from A meets the circumference in C and further delimits it. A and C co-ordinates fix on abscissa axis the entire diagram A' A B C C'.

Now draw on the diagram a vector I^{n} corresponding to the rated current of the engine, and find the intersection point P, which corresponds to the rated load.

We can also deduce the rated power factor from the angle between I^{n} and V vectors. Normally the working point falls below, but near to the tangential point.

NOTES

A simple method for determining the exact angle of a vector lies in drawing a quarter of a circumference with unitary radius, for instance of 10cm, as in fig. 25

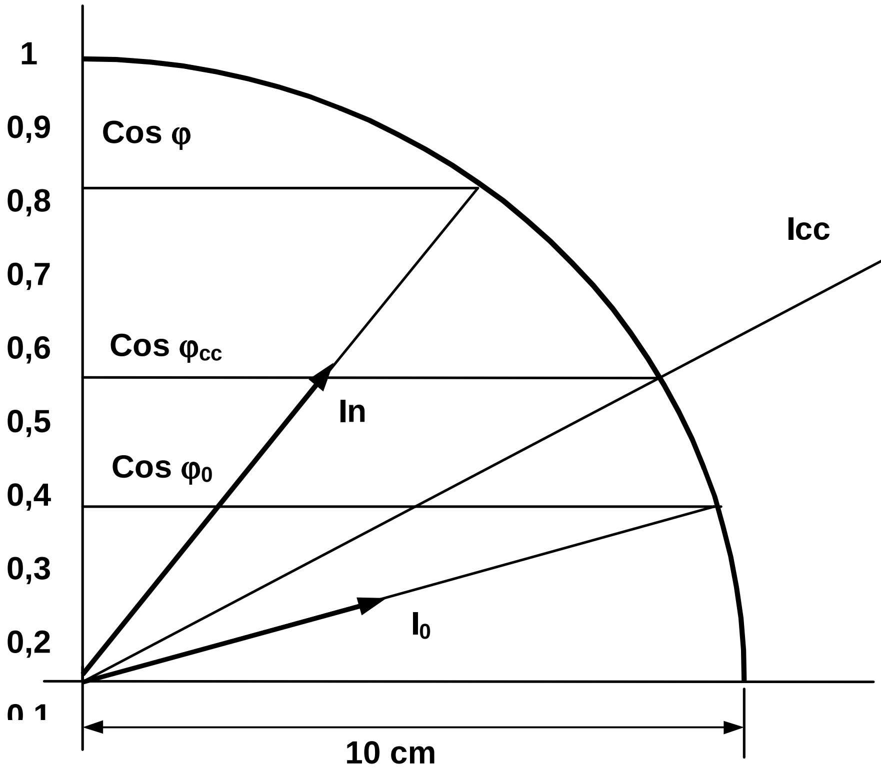

Fig. 25

After you have subdivided and graduated the ordinate in ten equal parts, in the range 0.1, 0.2,... 1, each step corresponds to the cosine of an unitary vector angle relative to the vertical axis.
Knowing the direction of the vector and projecting it on the vertical axis, the intercepted segment on the circumference gives you the cos φ value.
In our case we put the no load and short circuit power factors on the vertical axis and draw from these points two horizontal lines to meet the circumference.

So we'll find the direction of I^{c} and I^{cc} vectors.

CURRENTS

The circle diagram is based on the currents and lets you to read other important quantities, like power and torque.

In fact it is possible to read the absorbed current I, corresponding to OP segment, and the reaction current I', corresponding to AP segment in fig. 26

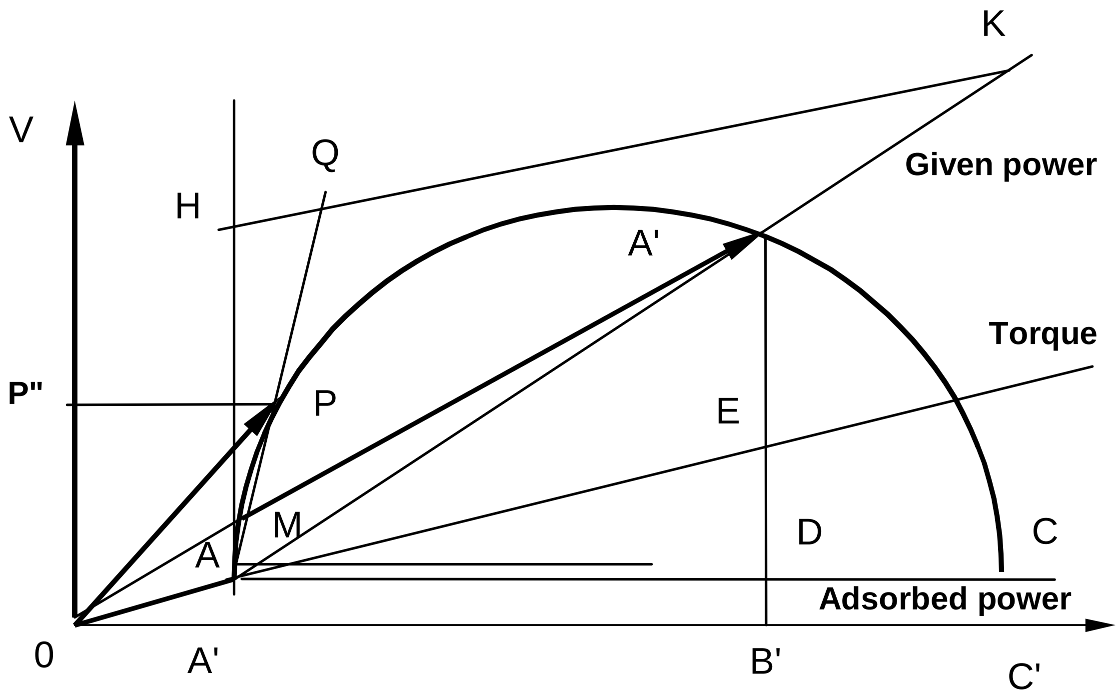

Fig. 26

The apparent absorbed power S is given by:

$$S = 3\ V\ I\ \cos\varphi\ ,$$

i.e. it is proportional to motor current by a factor 3 * V * cos φ ; therefore you can read the current measuring the current segment length and multiplying it by 3V.

From the transmitted power formula $P^t = K\ C$ it can be seen that power Pt and torque C are linearly related each other.

Therefore we can calculate the torque by dividing the power by the factor

$$K = 2\ n^0 /60 = 2\ f/\ p,$$

where n^0 is the synchronous speed, f is the frequency and p is the polar couples number.

Draw now from A a vertical line to point H and a parallel line to the AE line.

It meets on the prolongation of AB segment a point K, which determines the boundaries of the segment HK, also called the offset speed segment.

Extending AP till the point Q we find a segment HQ, which corresponds to the full load offset speed.

From a circle diagram we can deduce the typical characteristics of an asynchronous engine as a function of the useful power, and precisely:

SEGMENT	QUANTITY
P	Rotoric current
HQ	Offset speed
OP	Absorbed current
OP"	Cos φ
PP'	Absorbed power
PL	Torque

Fig. 27

POWERS

The apparent current absorbed by the motor is:

S = $\sqrt{3VI}$ and if V = constant, it is proportional to the current according to a coefficient $\sqrt{3V}$

Only for the reading of the segment of current, the diagram of the currents can be considered a diagram of the powers, but with a scale changed in the factor $\sqrt{3V}$

Power scale: 1cm = 3V u volt-ampere.

If you resolve the vector OP into the active component OP" = cos φ and in the reactive OP' = I sen f in the power scale, this segment represent respectively the active and the reactive power.

By the power scale you can also read:

$$AA = 3\ I_0 \cos \varphi 0$$

approximately equal to the mechanical and those in iron:

$$BB = 3\ V\ Icc \cos \varphi cc$$

equal to the short-circuit losses.

From BB' the segment DB' = Pm + P_{Fe} can be deduced and the segment BD represent the short circuit losses in the copper P_{Cu} (cc)

COUPLES

By the relation of the transmitted power Pt = Cwc the correspondence between this power and the motor couple at speed of synchronism can be obtained,
The two quantities are linearly proportional according to the coefficient W0,
The scale of the couples can be obtained dividing the powers scale as follows:

$$\omega o = 2 \pi no / 60 = 2 \pi f / p$$

where: f = frequency; p = polar couples.

The reading of the couples must be carried out corresponding to the network frequency and considering the AE as base.
For the working at nominal load the couple is given by the segment PL.

SHIFT

Draw a vertical line from A, determine a point H on it and draw a straight line going from this point in parallel to the base of the couples AE.

This straight line intercepts a second point K on the prolongation of AB, which delimits the shift segment HK.

In order to make the reading easier, the segment must be divided into 100 equal parts, giving a percentage graduation.

It is advised to choose a value of the length of HK, that can be easily divided.

If you prolong the segment AP till to reach Q, you will obtain the shift of the motor at full load by the segment HQ.

ASSIGNMENT N.9
PLOTTING THE MECHANICAL CHARACTERISTIC

THEORY

The circle diagram lets you draw this characteristic, which is very important when studying a motor.

It is related to the offset speed instead of to speed for the sake of simplicity.

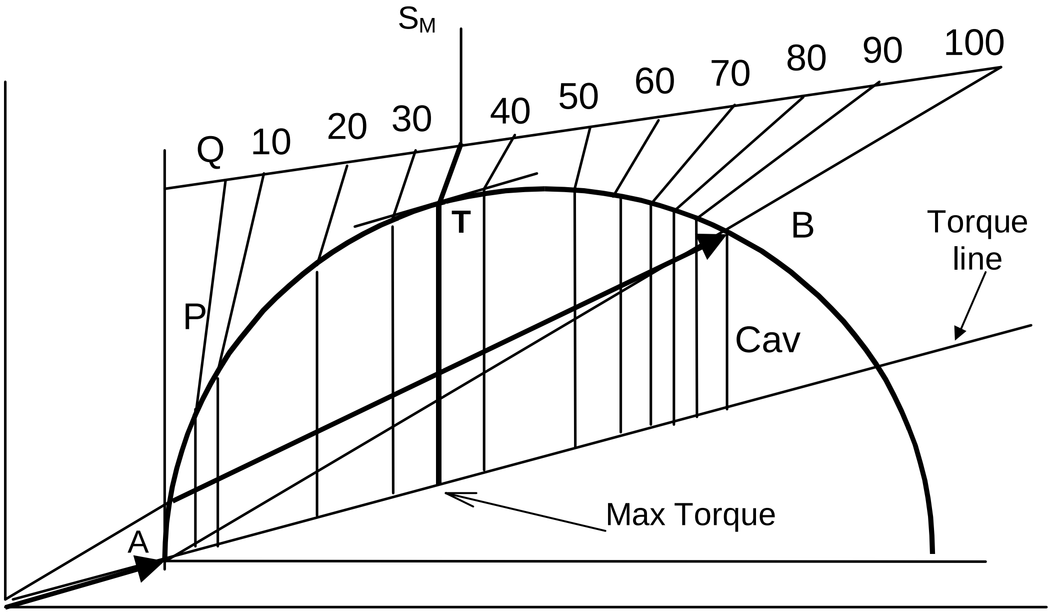

Fig. 28

Circle diagram for drawing the mechanical characteristic C = f(s).

Draw several segments like AQ according to 10%, 20%, ... 100% offset speed values, and find on the graph points like P.

Segments like PL will give the corresponding torque values, and we can draw the mechanical characteristic graph of fig 29

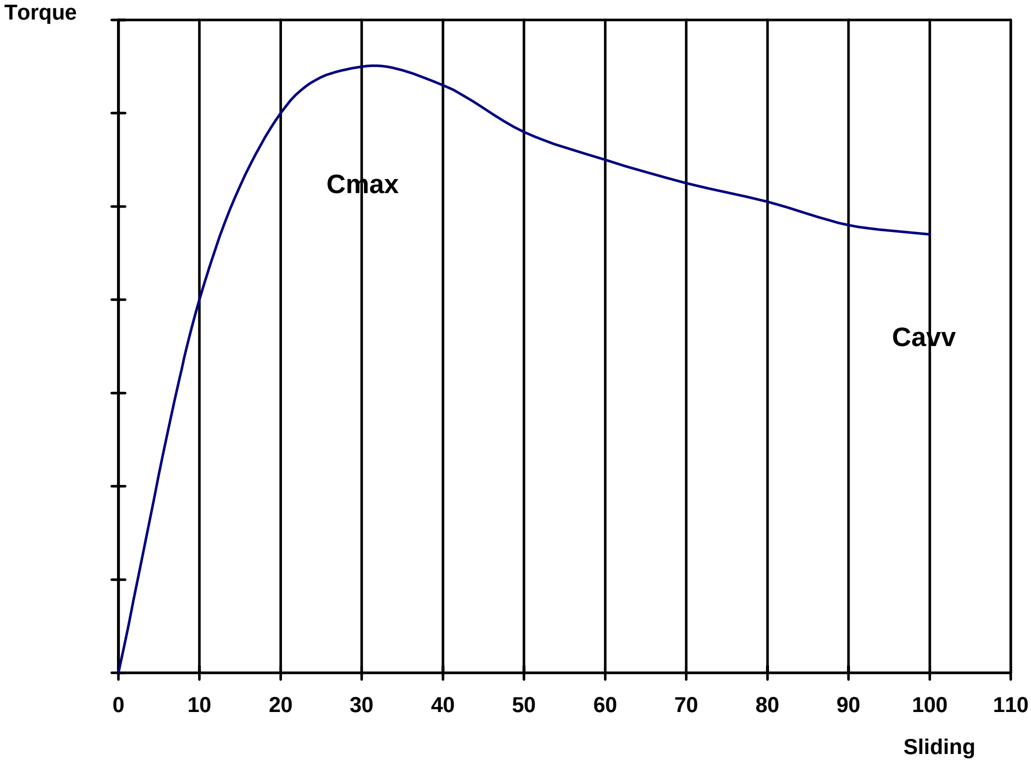

Fig. 29

Mechanical characteristic of an asynchronous motor.

From the graph we can immediately get the starting torque and the maximum torque.

If you want to improve the measurement of this latter, you can draw a tangent line, parallel to the couple line. So you find a point T, corresponding to the maximum torque and offset speed Sm

ASSIGNMENT N.10
DETERMINATION OF THE CONVENTIONAL EFFICIENCY

THEORY

The conventional efficiency is given by the percentage value n = (Pr/Pa) * 100. It can also be calculated by the following formula:

n = 100 - 100 . Pr / Pa,

where Pp is the sum of all losses, i.e.:

Pp = Pf + Pm + Pcu1 + Pcu2 + Pad;

These quantities are to be deduced from the graph in the following way:

- Pa: absorbed power corresponding to PP' segment;

- Pf: iron losses found in the no load test;

- Pcu1: stator copper losses, equal to 1.5 . Rm1 * I;

- Pt : transmitted power, equal to Pa - Pf - Pcu1;

- Pcu2: rotor copper losses, equal to 1.5 Rm2 * I^2 for a wound rotor, to S * Pt for a squirrel cage rotor;

- Pn: mechanical losses found in the no load test;

- Pad equal to 0.005 * Pr, where Pr is the approx. shaft power, equal to: Pr - Pcu2 - Pm;

- Pr : shaft power, equal to Pz - Pad;

You can draw a graph of the calculated values as a function of the load and get a typical shape, with a maximum approximately at 3/4 of the load.

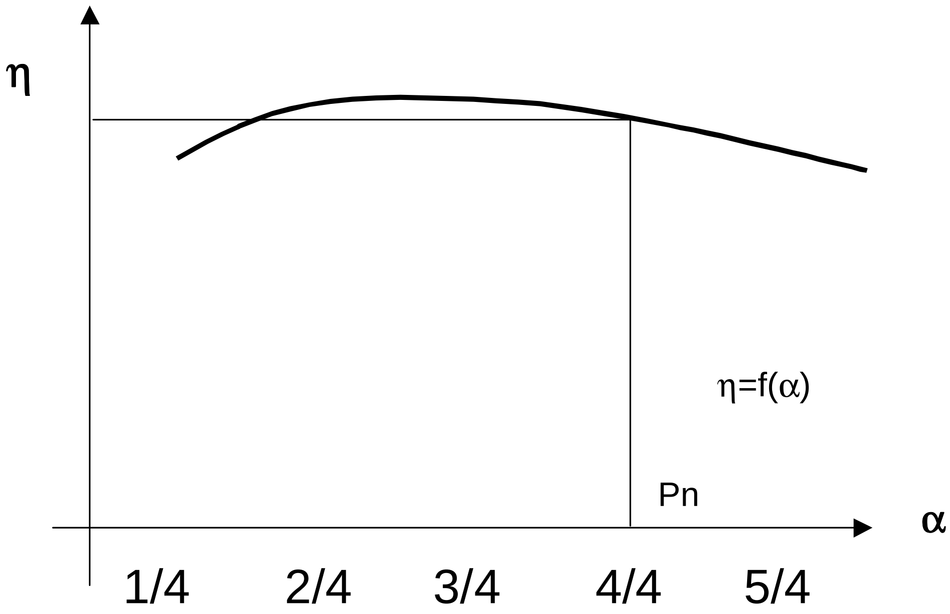

Fig. 30

NOTES

You must calculate the ohmic resistances for the copper losses for 75°C.

The additional losses can be calculated relying upon the approximate shaft power, because it coincides with the effective one.

Pr = Pt - Pcu2 - Pm - 0.005.Pr, and then:

Pr = (Pt - Pcu2 - Pm)/1.005.