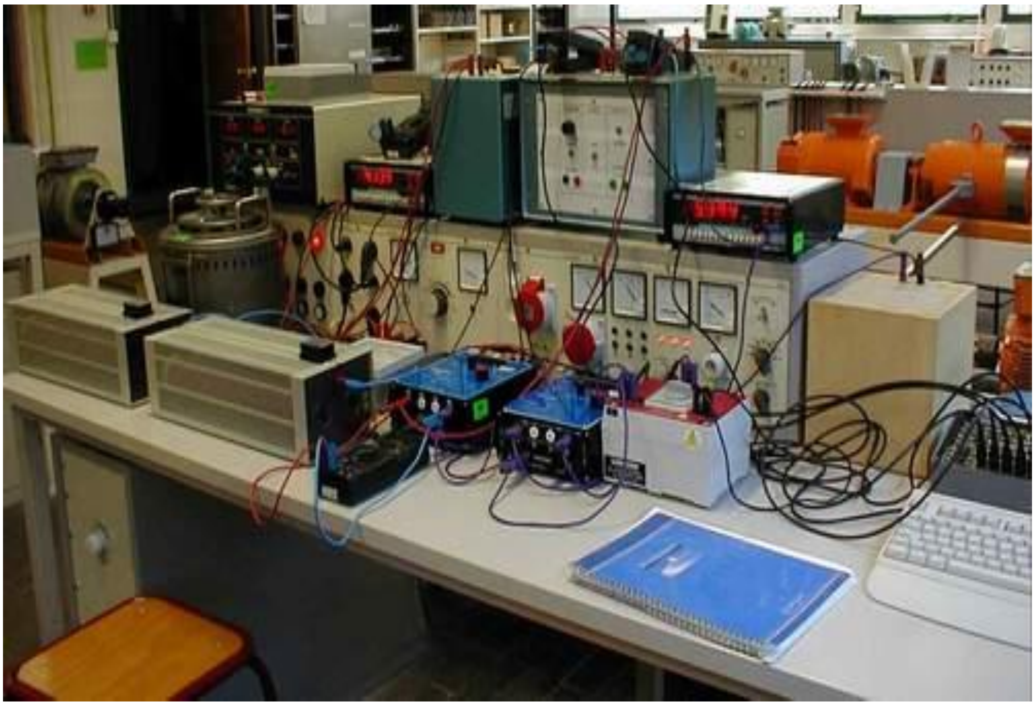
Department of Electrical Engineering
College of Engineering
University of Hail

Laboratory Manual
EE 206 – Electric Energy Engineering



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Experiment #1: Balanced Three-Phase Circuits

Part One: Three-phase Circuits: Y-; and Δ-Connection & Power Calculation

1. Objective:

- To connect three-phase loads as Wye, Y- connection and as Delta, Δ - connection.
- To verify the relationships between voltages and between currents of a three-phase circuits.
- To calculate the power for three-phase circuits.

2. Experiment components and measurement instruments:

- Three-phase AC power supply
- RMS meters
- Three-phase resistive load
- Three-phase inductive load
- Three-phase capacitive load
- Oscilloscope

3. Theory:

For Y- connection circuits, the relationships between the line and phase quantities are given by:

$$V_p = V_L / \sqrt{3} \quad (1)$$
$$I_p = I_L \quad (2)$$

Whereas the relationships for a Δ - connection are:

$$I_p = I_L / \sqrt{3} \quad (3)$$
$$V_p = V_L \quad (4)$$

The active and reactive powers for a 3-phase circuit (Y-connection or Δ-connection) are given by:

$$P = \sqrt{3}\, V_L I_L \cos\theta \quad (5)$$
$$Q = \sqrt{3}\, V_L I_L \sin\theta \quad (6)$$

And the complex power can be given by:

$$S = P + jQ \quad (7)$$

Where θ: Represents the power factor angle of the balanced load.

4. Three-Phase Circuits

4.1 Wye-connection

4.1.1 Circuit Diagram

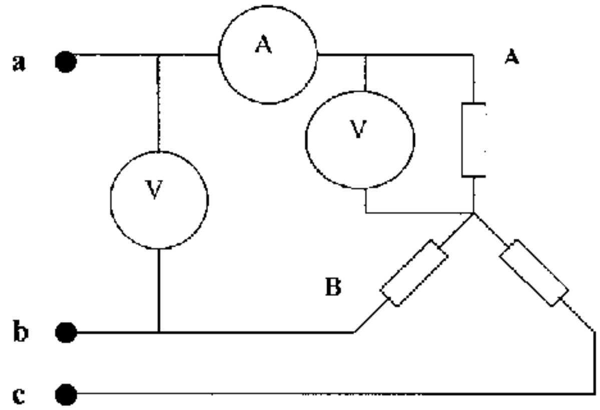


Figure 1: The Wye -Connection

4.1.2 Circuit Assembly
Assemble the circuit of the three-phase loads in Y connections according to the above circuit diagram.

4.1.3 Experiment Procedure
After the teacher has checked and approved the circuit, put the circuit into operation and follow the following steps:

1. Switch the load to unity power factor mode.
2. Select the balanced load from each phase.
3. With the load switch off turn the power supply on and adjust the line to neutral voltage to 127 V or the line voltage to 220 V.
4. Measure the line and phase voltages and currents for rated value of the load current and for unity power factor
5. Take two other sets of reading within the full load current.
6. Repeat step 4 and 5 for lagging and leading power factor.

4.1.4 Results Table
Enter the measured and calculated values into the following results tables!

4.1.4.1 Results Table for Unity Power Factor

R (%)	V_L (V)	V_P (V)	I_L (A)	I_P (A)	V_L/V_P	I_L/I_P
100%						
50%						
10%						

4.1.4.2 **Results Table for lagging Power Factor**

L=0.4 H	V_L (V)	V_P (V)	I_L (A)	I_P (A)	V_L/V_P	I_L/I_P
+100% of R						
+ 50% of R						
+ 10% of R						

4.1.4.3 **Results Table for Leading Power Factor**

C = 16 µF	V_L (V)	V_P (V)	I_L (A)	I_P (A)	V_L/V_P	I_L/I_P
+100% of R						
+ 50% of R						
+ 10% of R						

4.2 Δ - connection

4.2.1 Circuit Diagram

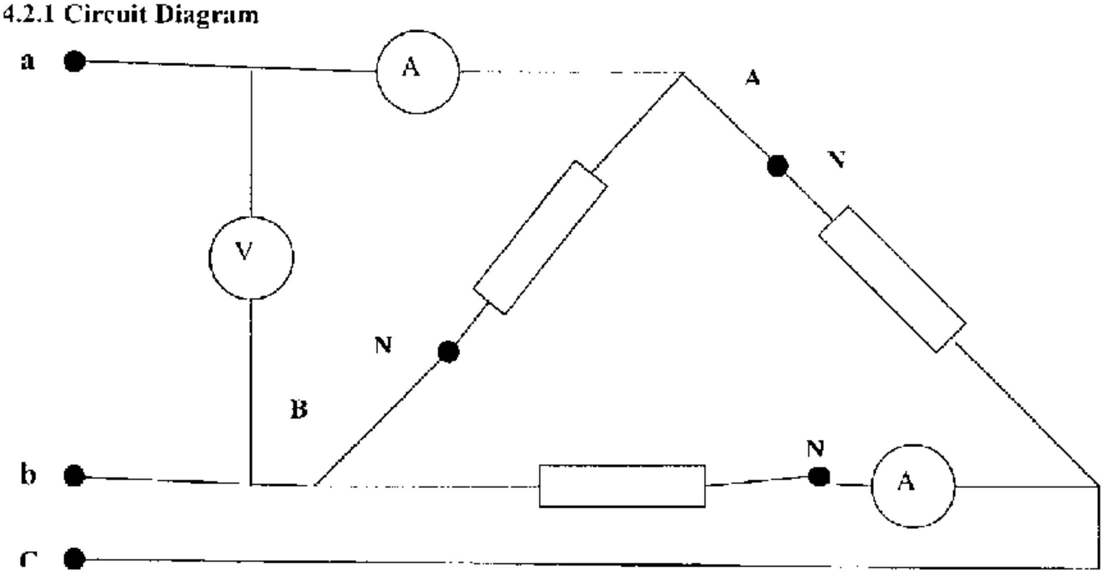


Figure 2: The Delta - Connection

4.2.2 Circuit assembly

Assemble the circuit of the three-phase loads in Δ - connections according to the above circuit diagram.

4.2.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation and follow the following steps:

1. Switch the load to unity power factor mode.
2. Select the balanced load from each phase.

3. With the load switch off turn the power supply on and adjust the line to line voltage to 120 V.
4. Measure the line and phase voltages and currents for rated value of the load current and for unity power factor
5. Take two other sets of reading within the full load current.
6. Repeat step 4 and 5 for lagging and leading power factor.

4.2.4 Results Table

Enter the measured and calculated values into the following results tables!

4.2.4.1 Results Table for Unity Power Factor

R (%)	V_L (V)	V_P (V)	I_L (A)	I_P (A)	V_L/V_P	I_L/I_P
100%						
50%						
10%						

4.2.4.2 Results Table for lagging Power Factor

L=0.4 H	V_L (V)	V_P (V)	I_L (A)	I_P (A)	V_L/V_P	I_L/I_P
+100% of R						
+ 50% of R						
+ 10% of R						

4.2.4.3 Results Table for Leading Power Factor

C = 16 μF	V_L (V)	V_P (V)	I_L (A)	I_P (A)	V_L/V_P	I_L/I_P
+100% of R						
+ 50% of R						
+ 10% of R						

5. Report

1. Complete the results tables above using equations 1-6.
2. Draw phasor diagrams showing the line and phase voltages currents for both Y and Δ connections.
3. Verify the relationships for the phase and line voltages and currents and state reasons for any errors

Part Two: Three-Phase Circuits: Measurement of Average Power

1. Objectives:

- To measure the average power supplied to a three-phase load connected in Y and in Δ
- To determine the power factor of the three-phase load.

2. Experiment components and measurement instruments:

- Three-phase AC power supply
- RMS meter
- Watt meters
- Three-phase resistive load
- Three-phase inductive load
- Three-phase capacitive load
- Oscilloscope.

3. Theory:

If two watt meters are used to measure the power supplied to a three-phase load, it can be shown that the watt meters will read:

$$P_1 = V_L I_L \cos(30^\circ + \theta) \quad (1)$$

$$P_2 = V_L I_L \cos(30^\circ - \theta) \quad (2)$$

Where

θ: Represent the power factor angle of the load.

From equations (1) and (2), the total power can be given:

$$P_T = P_1 + P_2 = \sqrt{3}\, V_L I_L \cos\theta \quad (3)$$

$$\tan\theta = \sqrt{3}\,(P_2 - P_1) / (P_1 + P_2) \quad (4)$$

4.1.1 Circuit Diagram

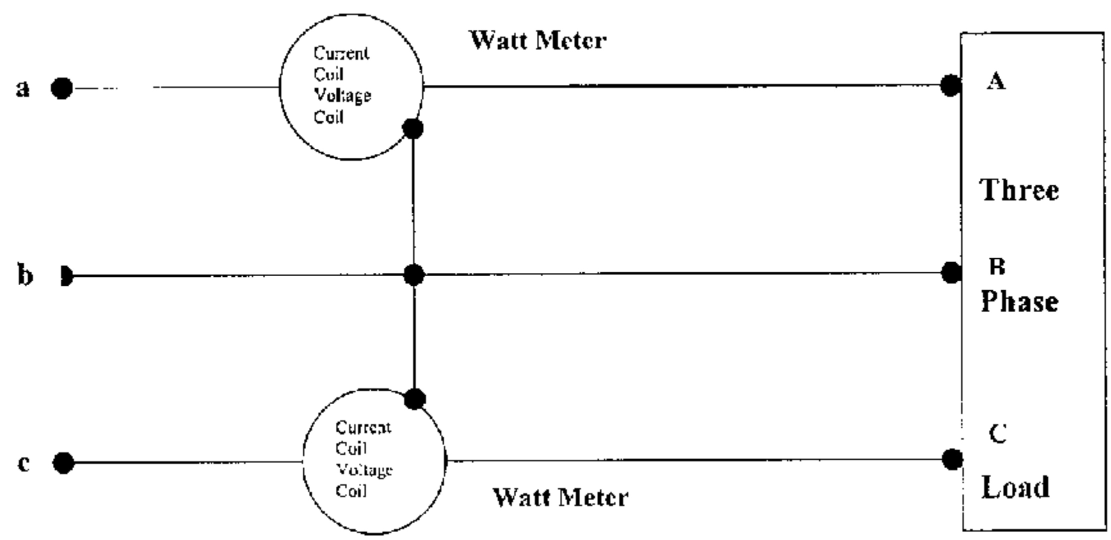


Figure 3: Two Wattmeter Connection

4.1.2 Circuit Assembly

Assemble the circuit for measuring the power of the three-phase load according to the above circuit diagram.

4.1.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation and perform the following steps:

a) Connect the three-phase load in Y

1. Set the supply voltage to about 220 V.
2. Select power factor of unity for the load.
3. Take three sets of reading, for the quantities shown in the table below, one at the rated value of the load current (calculate first the rated value of the load current), one at ½ rated load and one at ¼ rated.
4. Repeat step 3 for power factor lagging, as well as, power factor leading by arranging certain load combination.
5. Enter the results in results tables below!

b) Connect the three-phase load in Δ

1. Set the supply voltage to about 120 V ($V_L = V_P$ for Δ)
2. Repeat step 3 for unity and step 4 for power factor lagging and power factor leading.
3. Enter the results in results tables below!

4.1.4 Results Tables

Enter the measured and calculated values into the following results tables!

4.1.4.1 Results Table for Y-Connection Load and Unity Power Factor

R(%)	P1 (W)	P2 (W)	PT (W)	V_{AB} (V)	I_A (A)	P.F Mea.	P.F calc.	P.F error%	P_T Calc.	P_T error%
100%										
50%										
10%										

4.1.4.2 Results Table for Y-Connection Load and Power Factor lagging

L =0.4H	P1 (W)	P2 (W)	PT (W)	V_{AB} (V)	I_A (A)	P.F Mea.	P.F calc.	P.F error%	P_T Calc.	P_T error%
+ 100% of R										
+ 50% of R										
+ 10% of R										

4.1.4.3 Results Table for Y-Connection Load and Power Factor Leading

C= 16µF	P1 (W)	P2 (W)	PT (W)	V_{AB} (V)	I_A (A)	P.F Meas.	P.F calc.	P.F error%	P_T Calc.	P_T error%
+ 100% of R										
+ 50% of R										
+ 10% of R										

4.1.4.4 Results Table for Δ-Connection Load and unity Power Factor

R(%)	P1 (W)	P2 (W)	PT (W)	V_{AB} (V)	I_A (A)	P.F calc.	P_T Calc.	P_T error%
100%								
50%								
10%								

4.1.4.5 Results Table for Δ-Connection Load and Power Factor Lagging

L=0.4H	P1 (W)	P2 (W)	PT (W)	V_{AB} (V)	I_A (A)	P.F calc.	P_T Calc.	P_T error%
+ 100% of R								
+ 50% of R								
+ 10% of R								

4.1.4.6 Results Table for Δ-Connection Load and Power Factor Leading

C= 16μF	P1 (W)	P2 (W)	PT (W)	V_{AB} (V)	I_A (A)	P.F calc.	P_T Calc.	P_T error%
+ 100% of R								
+ 50% of R								
+ 10% of R								

Note: At a certain power factor, one of the watt meters may try to read backwards. In this case, switch off the supply, then reverse the connection of either the voltage coil or the current coil of the wattmeter. Mark the reading as negative value.

5. Report:

1. Using the equations 1 - 4 to do the necessary calculation for filling the above results Tables above.
2. Comment on the levels of error between the computed and measured values.
3. Draw a phasor diagram and explain why equations (1) and (2) can be used to calculate the total power. Draw only for rated load, 0.8 power factor lagging.

Experiment #2: Magnetic Circuits

1. Objective:

- To determine the B-H characteristics of an iron core.
- To find the relative permeability (**μ_r**) of an iron core.
- To calculate the reluctance (**R**) of the iron core

2. Experiment components and measurement instruments:

- Rectangular laminated core.
- Coil
- Voltmeter
- Ammeter
- Variable AC supply

3. Theory

If a current of **I** A flows from a supply of **E** volts through a coil of **N** turns wound on a magnetic core of an average length **Lc**, the magnetic field intensity can be written as:

$$H = N\,I / Lc \qquad (1)$$

From Faraday's law of electromagnetic induction, the rms values of the induced voltage across the coil, **E** is:

$$E = \omega N \Phi \qquad (2)$$

since

$$\Phi = AB \qquad (3)$$

therefore

$$E = \omega N\,AB \qquad (4)$$

and

$$B = \mu_r\,\mu_o\,H \qquad (5)$$

From equations 1, 4 and 5 it is clear that **E – I** characteristic of the core is equivalent to its **B-H** characteristic. Further, it can be shown that,

$$E = \omega N^2 A \mu I / Lc \qquad (6)$$

Where the permeability of the core can be written as:

$$\mu = \mu_r\,\mu_o \qquad (7)$$
$$\mu_o = 4\pi \times 10^{-7} \text{ (H/m)}$$

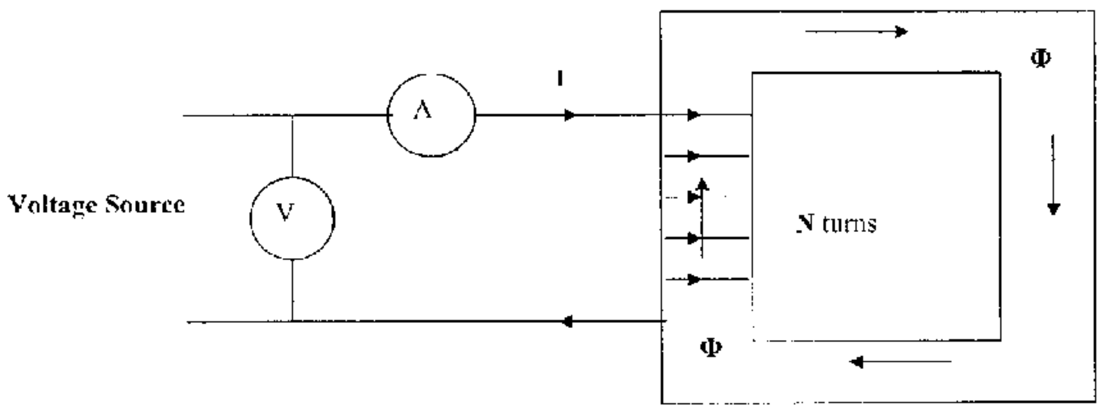
and it is given by:

$$\mu = E\,Lc / \omega N^2 A\,I \qquad (8)$$

Finally, the reluctance of the core can be express as:

$$R = NI / \Phi = Lc / \mu_r\, \mu_o\, A \qquad (9)$$

4. Circuit Diagram



Dimensions: Lc m; and A m^2

Figure1: A simple Magnetic Core Circuit

4. Circuit Assembly

Assemble the magnetic circuit according to the above circuit diagram.

6. Experiment Procedure

1. Find the typical dimensions of the magnetic core. The instructor may help to get the accurate number of turns of the coil.
2. Set the input voltage first to 10V. Record the corresponding current.
3. Repeat step 2 up to 150 V in steps of 10 V.

7. Results Table

Enter the measured and calculated values into the following results tables!

7.1 <u>Results Table</u>

E (V)	I (A)	K = E / I (V/A)	μ_r	R (1/H)
10				
20				
:				
150				

8. Report

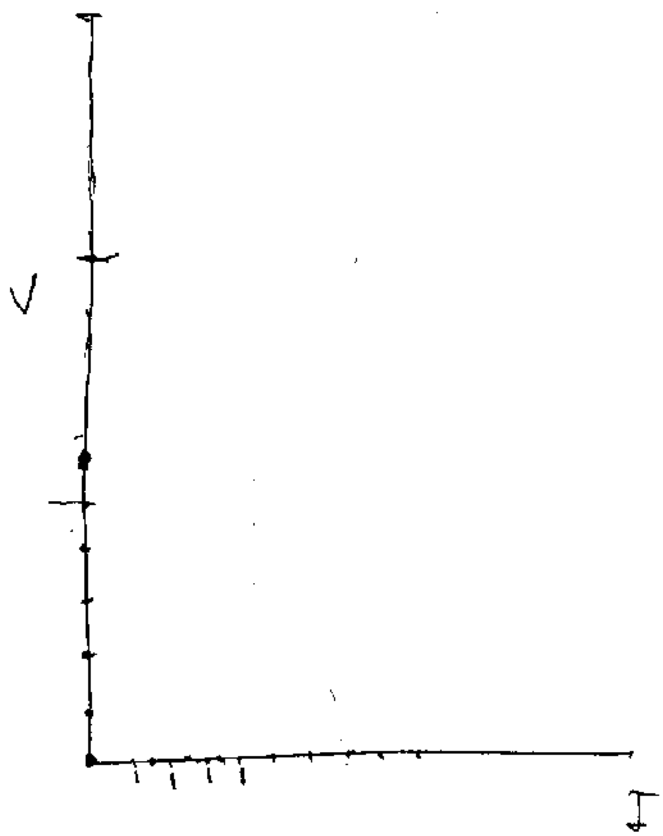
1. Plot **E** versus I on a graph paper
2. Calculate **K**, μ_r and R for each reading and complete the above results table.
3. Plot μ_r and **R** as functions of I.

<u>Note</u>: Magnetic core dimensions are:

Lc =

Ac =

N = 250 turns



Experiment #3: Single-phase Transformers

1. Objective:

- Study the response of the single-phase transformer;
- At no-load,
- At short-circuit, and
- Under load condition.
- Determination of the parameters of the transformer's equivalent circuit.
- Calculation of the efficiency of the transformer and,
- Calculation of the voltage regulation under different load conditions.

2. Experiment components and measurement instruments:

- Single-phase transformer
- Power meter
- RMS meters
- Resistive load
- Inductive load
- Capacitive load
- Oscilloscope

3. Theory:

In order to investigate the behavior of a transformer under various loads, an examination of a single-phase transformer model or one phase of a three-phase transformer suffices. The function of a transformer is based on the law of induction, which states that a voltage is induced in a stationary coil when it is permeated with a time-varying magnetic flux.
If the magnetic flux simultaneously permeates two windings with number of turns w_1 and w_2, then in the case of an ideal transformer (i.e. without leakage) the following applies for the corresponding voltages:

$$\frac{U_1}{U_2} = \frac{w_1}{w_2} = t$$

Consequently the following relationship exists for the current:

$$\frac{I_1}{I_2} = \frac{w_2}{w_1}$$

Because of this so-called **power balance** the following generally applies to transformers:

$$\frac{U_1^2}{Z_1} = \frac{U_2^2}{Z_2} = \text{const.}$$

and further it follows that:

$$\frac{Z_1}{Z_2} = \frac{U_1^2}{U_2^2} = t^2$$

Impedance on one side of the transformer thus appears with different value on the other side; the same also holds true for equivalent resistances and reactances. This fact is referred to as a so-called **resistance transformation.**

3. Responses under No-Load, Short-Circuit and Load Conditions

3. 1 Response at no-load

At no-load the winding 1 is fed with nominal voltage; winding 2 remains disconnected. A current I10 flows, which is primarily required to build up the magnetization of the so-called magnetizing reactance X_h.
With the copper losses V_{Cu} taken into account (caused by the ohmic resistance R_1 of the primary winding) as well as the iron losses V_{Fe} (caused by the total loss mass density in the iron core and represented as active current by an imaginary ohmic resistance R_{Fe}) the following equivalent circuit diagram is produced:

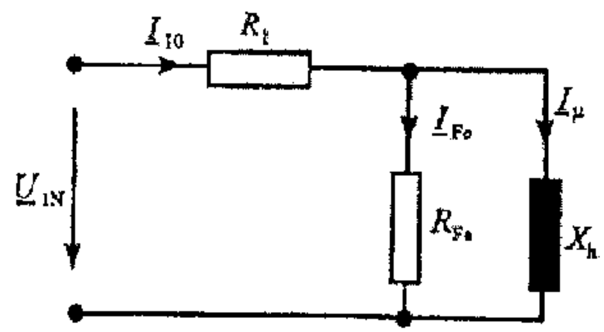


Fig. 1: Equivalent circuit diagram of a transformer operating at no-load

Using the no-load experiment it is possible to directly determine the magnitude of the magnetizing reactances X_h of the transformer's equivalent circuit diagram.
The variables R1 and R_{Fe} cannot be measured separately. In order to determine the resistance of the primary winding, a measurement bridge (DC voltage measurement) has to be used, for example. However, in large transformers the relationship $R_1 << R_{Fe}$ always applies so that the copper resistance can be neglected at least in no-load operation.

3. 2 Response to short-circuit

Here the transformer is short-circuited on the secondary side and a (small) voltage is applied to the primary side which is just enough so that the normal current flows. Due to the magnetizing reactance the current is negligibly small, because this is practically shorted out on account of the short - circuit on the secondary side. Now a lot more leakage reactances arise, which function as inductive reactances in the lines.
The following equivalent circuit diagram results:

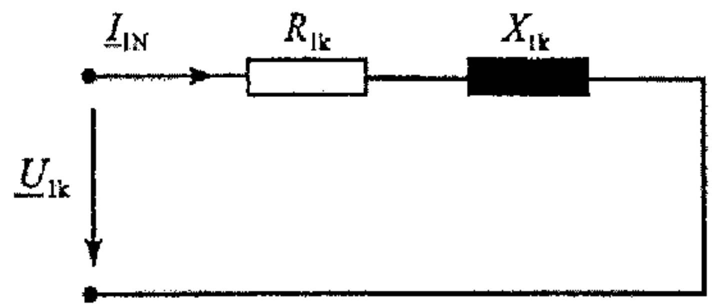


Fig. 2: Equivalent circuit diagram of a transformer operating with a short-circuit

The following quantities were introduced anew into the above equivalent circuit diagram:

$$R_{1k} = R_1 + R_2' \quad \text{and} \quad X_{1k} = X_{1\sigma} + X_{2\sigma}'$$

The quantities above denote:
U_{1k}: applied primary voltage, which leads to the nominal current
R_2: ohmic resistance of the secondary side
$R_{2'}$: value of R_2 converted to the primary side in accordance with the expression
$R_{2'} = R_2 . t^2$
$X_{1\sigma}$: leakage reactance of the primary side
$X_{2\sigma}$: leakage reactance of the secondary side
$X_{2\sigma'}$: value of $X_{2\sigma}$ converted to the primary side in accordance with the expression
$X_{2\sigma'} = X_{2\sigma} . t^2$

Primary and secondary windings are designed for the same power and required the same winding space; consequently they demonstrate the same leakage. Thus the following holds true: $R_1 = R_{2'}$ and $X_{1\sigma} - X_{2\sigma'}$

The two variables R1k and X1k are combined into the so-called short-circuit impedance Z1k, for its magnitude the following applies:

$$Z_{1k} = \sqrt{R_{1k}^2 + X_{1k}^2} = \frac{U_{1k}}{I_{1N}}$$

In the case of short-circuit with the nominal current on the primary side, the active power consumed amounts to:

$$P_{1k} = R_{1k} \cdot I_{1N}^2 = U_{1k} \cdot I_{1N} \cdot \cos \varphi_k$$

Where φ_k: phase angle of the current for short-circuit.

3.3 Response under load operation

During "load operation" we are referring to a load condition which falls into the range of

standard transformer loads, i.e. a current, which is considerably larger than the no-load current; but also significantly smaller than the short-circuit current.
The equivalent circuit diagram for this operation can be put together as a combination of the above representations derived for no-load and short-circuit.
Fig. 1.4 reproduces this after converting the quantities for the secondary side to the primary side:

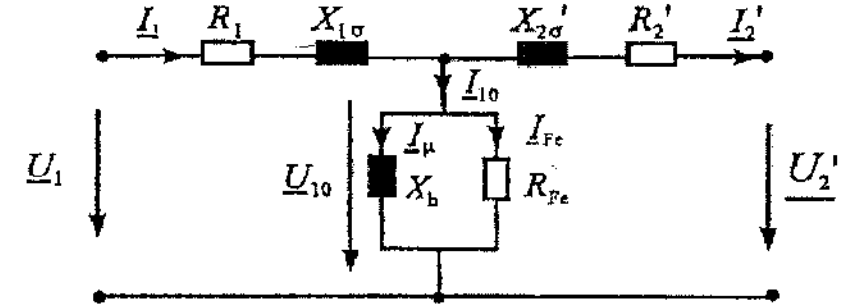


Fig. 3: Equivalent circuit diagram for the transformer operating under load

We can read off the following values from the equivalent circuit diagram:

$\underline{U}_1 = \underline{U}_2' + \underline{I}_2' \cdot (R_2' + j\, X_{2\sigma}') + \underline{I}_1 \cdot (R_1 + j\, X_{1\sigma})$ and $\underline{I}_1 = \underline{I}_2' + \underline{I}_{10} = \underline{I}_2' + \underline{I}_\mu + \underline{I}_{Fe}$

These results in the following phasor diagram under load (here for the case of a mixed resistive-inductive load; as is most frequently the case):

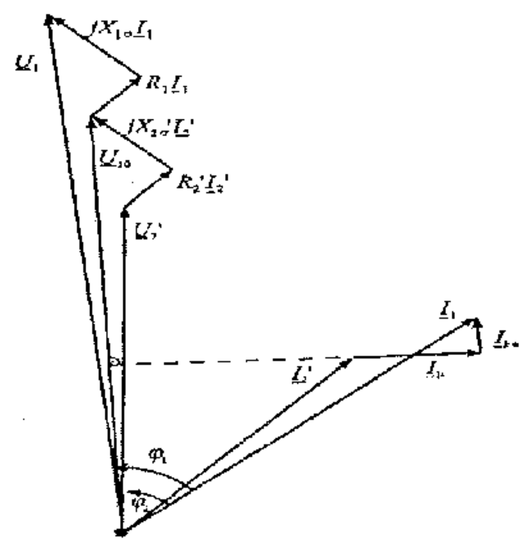


Fig. 4: Complete phasor diagram of the transformer operating under mixed resistive-inductive load

3.4 Efficiency and Voltage regulation of the transformer

For the operating case under investigation we obtain the efficiency η and the voltage regulation **VR** as follows:

$$\eta \% = P2 / P1 \times 100$$

and

$$VR \% = (U1 - U2') / U2' \times 100$$

4. Response at no-load

4.1 Experiment Objective:

To determine the voltage transformation ratio of the transformer for various primary voltages operation at no-load; determination of the variables which can be derived from the equivalent circuit diagram for normal voltage at primary winding.

4.2 Circuit Diagram

Set up the experiment circuit in accordance to Fig. 5.

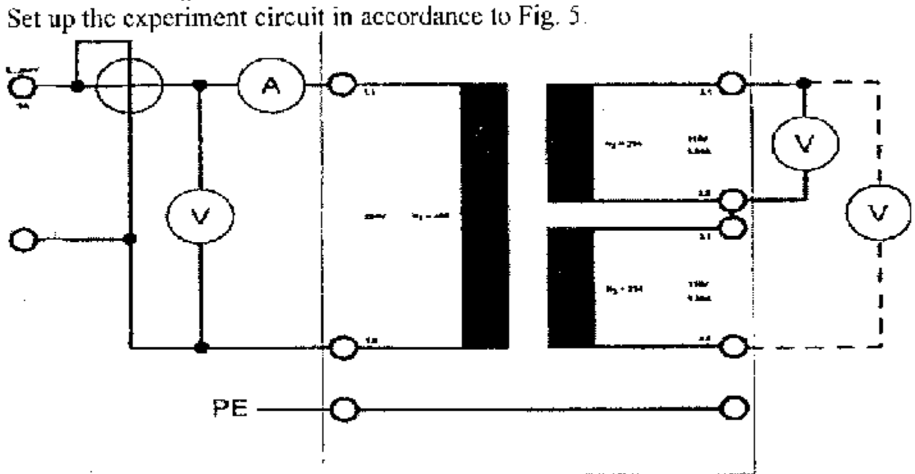


Fig. 5: Circuit used for investigating no-load response

4.3 Experiment Procedure:

Set the experiment transformer to the voltages for U_1 listed in the table, and measure the corresponding values for U_2, U_{23}, P_{10}, and I_{10}. Calculate the transformer ratios t_{12}, and t_{123} for each input voltage U1 as follows:

$$t_{12} = U_1 / U_2 \qquad t_{123} = U_1 / U_{23}$$

U1 (V)	U2 (V)	U23 (V)	P_{10} (W)	I_{10} (A)	t_{12}	t_{123}
50						

100						
150						
200						
230						

Transfer the results from the above Table into the following diagram, and plot graph of the voltage transformation for various input voltages!
Enter the corresponding transformation ratios onto the characteristic curves.

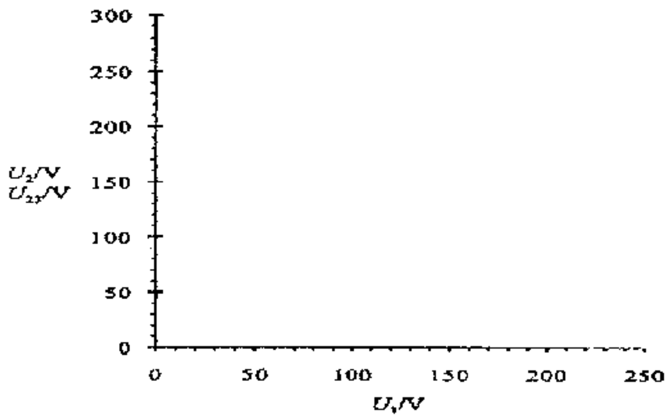


Fig 6: Diagram on the no-load response of the single-phase transformer

4.4 Calculation:
Determine the variables for the equivalent circuit diagram with nominal voltage (U1 = 230 V).
Active and reactive components of the no-load current:

$$cos\varphi_0 = \frac{P_{10}}{U_1 \cdot I_{10}} = \qquad\qquad cos\varphi_0 =$$

$$I_{FE} = I_{10} \cdot cos\varphi_0 = \qquad\qquad I_{FE} =$$

$$I_\mu = I_{10} \cdot sin\varphi_0 = \qquad\qquad I_\mu =$$

Fictitious core resistance and magnetizing reactance are calculated with the following equations:

$$R_{FE} = \frac{U_1}{I_{FE}} = \qquad\qquad R_{FE} \quad =$$

$$X_h = \frac{U_1}{I_\mu} = \qquad\qquad X_h \quad =$$

5. Response to short-circuit

5.1 Experiment objective:
Measurement of voltage, current and active power for secondary-side short-circuits of the transformer and determination of the variables which can be derived from the equivalent circuit diagram. Determination of the current transformation ratio. Determination of the short - circuit voltage.

5.2 Circuit Diagram:
Set up the experiment circuit in accordance with Fig. 7

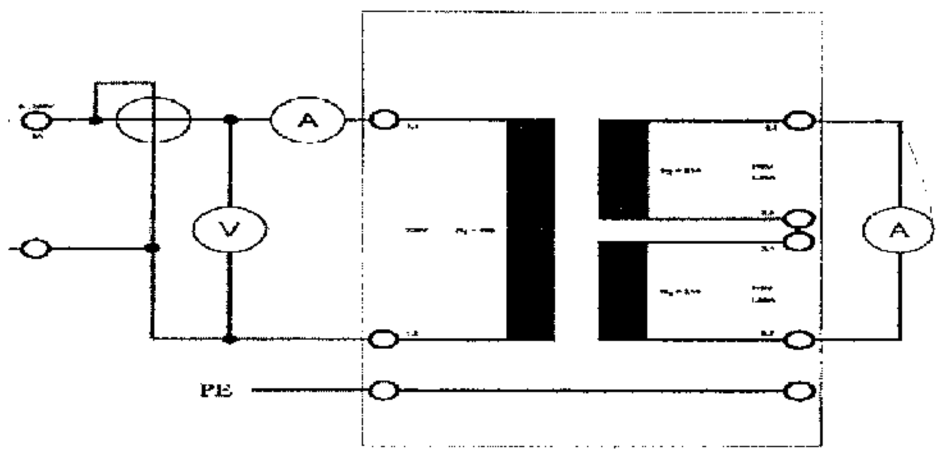


Fig. 7: Circuit for investigating short-circuit response

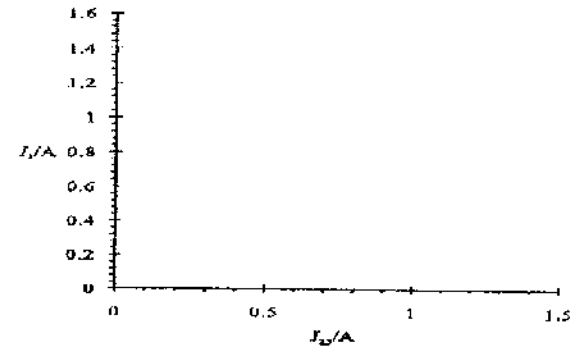
5.3 Experiment Procedure:
In order to record the current I_{23} connect the ammeter to the sockets 2.1 and 3.2. Carry out the measurements beginning with the low current values for I23. Compute the current transformation ratio t_{I123} as follows:

$$t_{I123} = I_1 / I_2$$

I_{23} (A)	I_1(A)	U_{1K} (V)	P_{1K} (W)	t_{I123}
0.3				

0.6				
0.9				
1.2				
1.36				
1.5				

Transfer the results from the table above into the following diagram, and plot a graph of the current transformation for various input currents! In a second diagram plot a graph of the consumed active power versus the primary current.



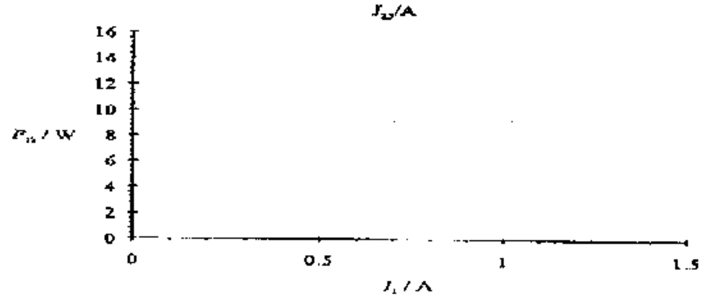


Fig. 8: Diagram for short-circuit response of the single-phase transformer

5.4 Calculation:

Determine cos φ_K the resistive and inductive component of the short-circuit impedance in accordance with the equations (for In = 1.36 A)

$$cos\varphi_k = \frac{P_{1k}}{U_{1k} \cdot I_1} = \qquad\qquad cos\varphi_k =$$

$$R_{1k} = \frac{U_{1k} \cdot cos\varphi_k}{I_1} = \qquad\qquad R_{1k} =$$

$$X_{1k} = \frac{U_{1k} \cdot sin\varphi_k}{I_1} = \qquad\qquad X_{1k} =$$

Calculate the relative short-circuit voltages for the single-phase transformer (for secondary-side nominal current).

$$u_k = \frac{U_{1k}}{U_{1N}} = \qquad\qquad u_k \quad =$$

$$u_r = u_k \cdot cos\varphi_k = \qquad\qquad u_r \quad =$$

$$u_x = u_k \cdot sin\varphi_k = \qquad\qquad u_x \quad =$$

(In the case of short-circuit measurements the influence of the magnetizing inductance X_h and the fictitious core loss resistance R_{Fe} can be disregarded).

Draw a complete equivalent circuit diagram of the transformer and enter all of the measured or calculated variables (in accordance with the note provided in the theoretical section the following holds true as an approximation: $R_1 = R_{2'}$ and $X_{1\sigma} = X_{2\sigma'}$).

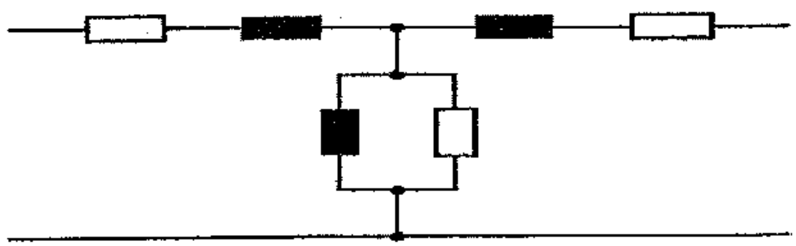


Fig. 9: Equivalent circuit diagram of the single-phase transformer

6. Response during load operation

6.1 Experiment objective:

Measure how the load type and magnitude affect the response of the secondary voltage and compare this to the values expected theoretically. Determine the efficiency and voltage regulation.

6.2 Circuit Diagram:

Set up the experiment circuit as shown in Fig. 10. First, only connect the resistive load.

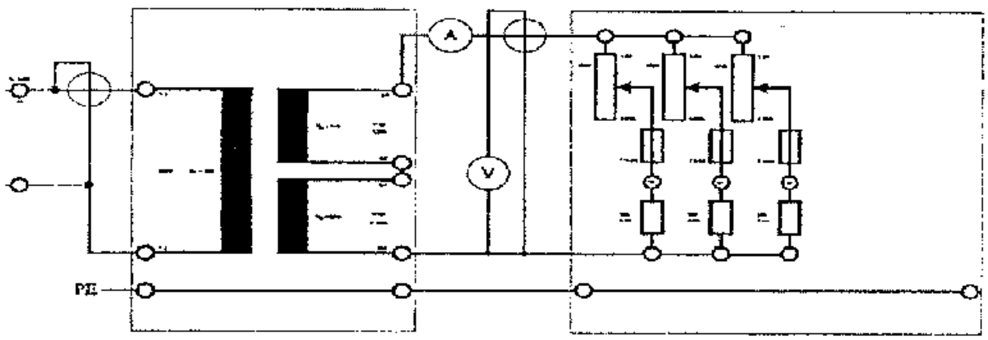


Fig. 10: Circuit for investigating load response

6.2 Experiment Procedure

Carry out the measurement at a primary voltage of 230 V. First, set the resistance of the ohmic load to 100%. Measure the variables listed in the following table for resistance values indicated there. The variables not directly measurable are determined as follows: the efficiency is calculated of the ratio of the output power (P_2) to the absorbed power (P_1).

$$\eta = \frac{P_2}{P_1} \cdot 100\% \qquad \Delta U = U_{230} - U_{23}$$

R (%)	U230(V)	U23(V)	ΔU(V)	I2(A)	P1(W)	P2(W)	η (%)
100							
80							
60							
40							
20							
10							
7.5							

Plot a graph of the efficiency curve versus the secondary current!

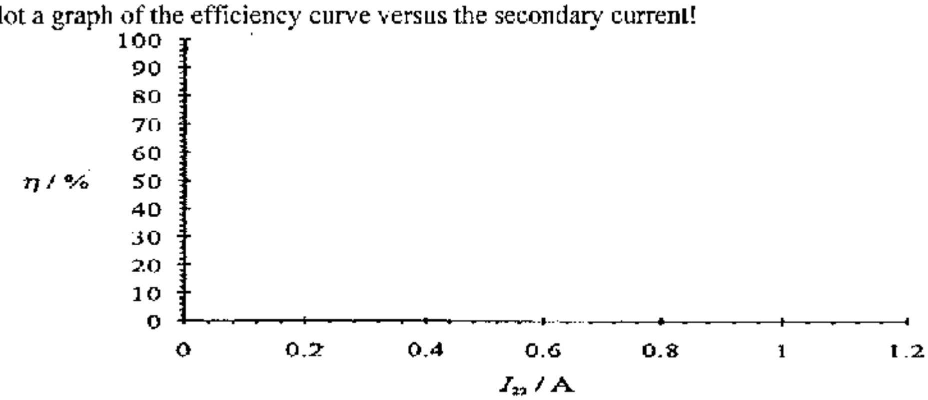


Fig. 11: Efficiency curve of the single-phase transformer under load

Now carry out the experiment with inductive and capacitive load. The inductive load of 0.6 H and 0.5 H is set up by connecting two each of either 1.2 H or 1.0 H in parallel.

L(H)	U_{230}(V)	U_{23}(V)	ΔU(V)	I_2(A)
6				
4.8				
2.4				
1.2				
1				
0.8				
0.6				
0.4				

C(μF)	U_{230}(V)	U_{23}(V)	ΔU(V)	I_2(A)
2				
4				
8				
16				

Plot the voltage curves under load with R, L and C loads versus the current in a graph!

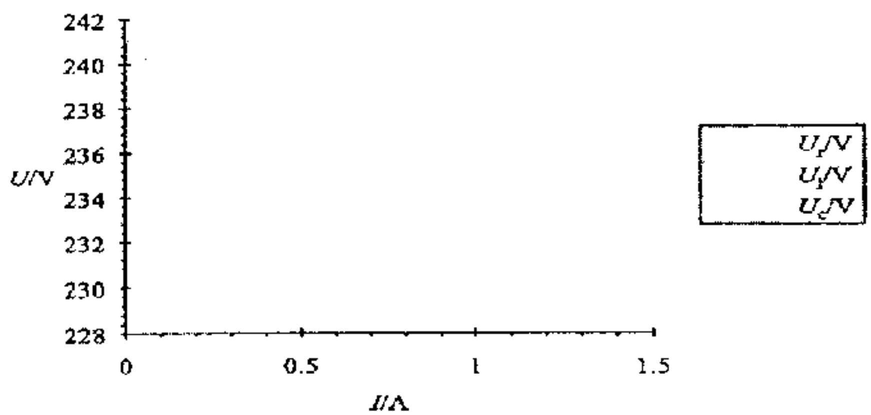


Fig. 12: Voltage curve of the single-phase transformer under load

Experiment # 4: Multi-Function DC Machine as a Shunt and a Compound Wound Generator

1 Objectives: To study the following for the multi-function machine operates as Shunt and Compound wound Generator

- Operating the separately – excited DC Shunt Wound Generator and Recording the No-load Characteristics, $U_0 = f(I_E)$ with n = constant, $U_0 = f(n)$ with I_E = constant
- Operating the Self-excited DC Shunt Generator and recording the no-load characteristics $U_0 = f(I_E)$ with n = constant, $U_0 = f(n)$ with I_E = constant
- Plotting the no-load characteristics
- Recording load characteristics for separately and Self-excited DC Shunt Wound Generator
- Plotting the Characteristics
- Recognizing and Explaining the Differences in Generator behavior for separately and Self-excitation
- Recording Load Characteristics for Separately - excited DC Compound Wound Generator
- Plotting the characteristics

2. Experiment components and measurement instruments:

- DC Stabilizer
- on /off Switch Three Pole
- Compound Wound Motor (uses as a driver)
- Shunt Wound Generator
- Starter
- Ohmic Load
- Magnetic powder brake
- Tacho generator
- RMS meters
- Speed-Torque Indicator
- Digital tachometer

3. No-Load Characteristics

- **$U_0 = f(I_E)$ with n = Constant and $U_0 = f(n)$ with I_E = Constant for Separately-Excited DC Shunt Wound Generator**
- **$U_0 = f(I_E)$ with n = Constant and $U_0 = f(n)$ with I_E = Constant for Self-Excited DC Shunt Wound Generator**

3.1 Theory:

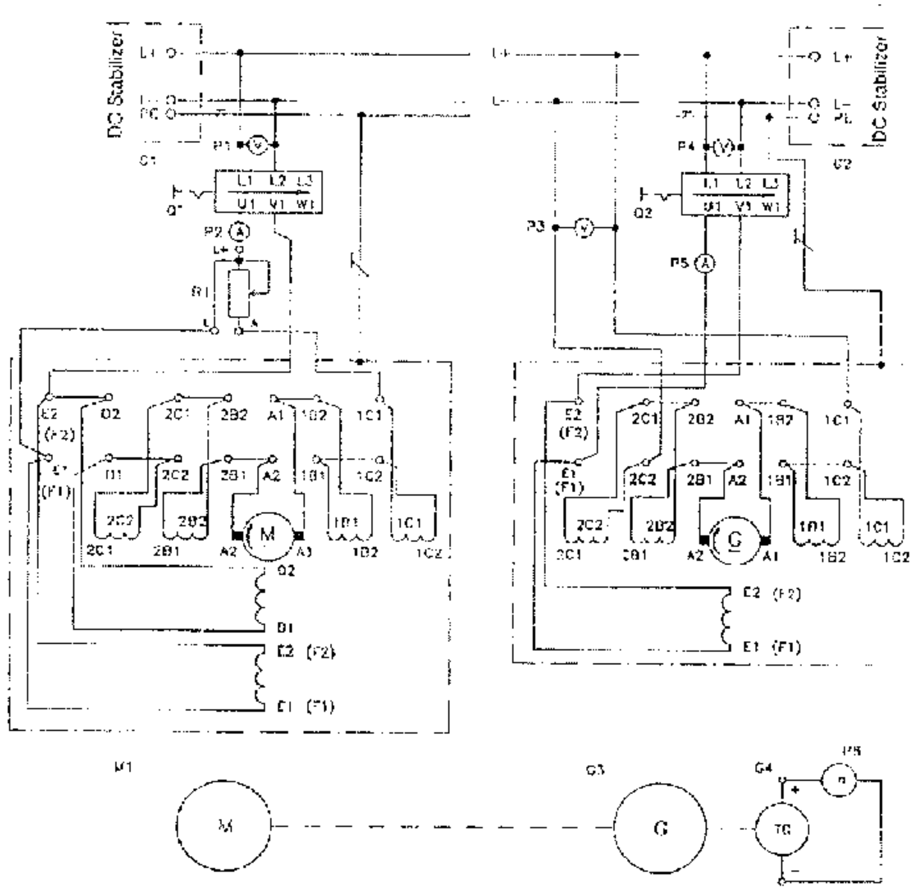
The electromotive force in the armature of a DC generator in accordance with the basic generator is given by the following equation:

$$U_0 \sim \Phi \cdot n$$

where: U_0 = electromotive force
$\Phi = f(I_E)$ magnetic flux
n = speed of generator armature

3.2 Recording the No-load Characteristic $U_0 = f(I_F)$ for Separately-Excited DC Shunt Wound Generator

3.2.1 Circuit Diagram



3.2.2 Circuit Assembly

Connect the motor M_1 with generator G_3 and tachogenerator G_4. Connect the DC compound wound machine as the driving motor and the DC shunt wound machine as generator for clockwise rotation as specified in the circuit diagram. Assemble the circuit.

3.2.3 Experiment procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Switch on the DC compound wound motor using switch Q_1.

Vary the resistance on the starter R_1, so that a speed of 2000 min^{-1} is indicated on the speed display P_6. If necessary reduce the voltage on the voltage supply G_1. Keep this speed constant while determining the desired measured values.
Using switch Q_2 switch on the voltage supply G_2 and set the exciter voltage at measurement instrument P_4 and subsequently the exciter current at measurement instrument P_5 to values specified in the tables. Additionally, measure the desired values of the generator voltage U_0 at measurement instrument P_3 as well as the exciter voltage U_E at measurement instrument P_4 and enter these values into the tables below.

3.2.4 Result Tables

3.2.4.1

DC Shunt Wound Generator 1.0, Separately-Excited										
Setting with Starter R_1, $n=2000^{-1}$ Constant										
Setting at the Voltage Supply G_2										
I_E (mA)	0	25	50	75	100	125	150	200	250	300
Measurement U_0 (V)										
U_E (V)										

3.2.4.2 Plot of the No- load Characteristics at constant speed n

Using the measured values of U_0 (V), and I_E (mA), draw the no-load characteristics of the separately –excited DC Shunt wound generator for a constant value of speed n.

3.3 Recording the No-load Characteristics $U_0 = f(n)$ for Separately-excited DC Shunt Wound Generator

3.3.1 Circuit Diagram

The circuit diagram from section 3.2 is used

3.3.2 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Switch on the DC compound wound motor using switch Q_1.
Vary the speed in accordance with the tables by reducing the voltage on the voltage supply G_1 or by changing the resistance value on the starter R1. Determine the speed on the speed display P_6.
Using switch Q_2 switch on the voltage supply G_2 and set the exciter voltage at measurement instrument P_4 and subsequently the exciter current $I_E = 0.3$ A at measurement instrument P_5. Keep the exciter current constant while determining the desired measurement values. Measure the desired values of the generator voltage U_0 at measurement instrument P_3 and enter these values into the table below.

V_E								
I_E								

3.3.3 Results Table

3.3.3.1

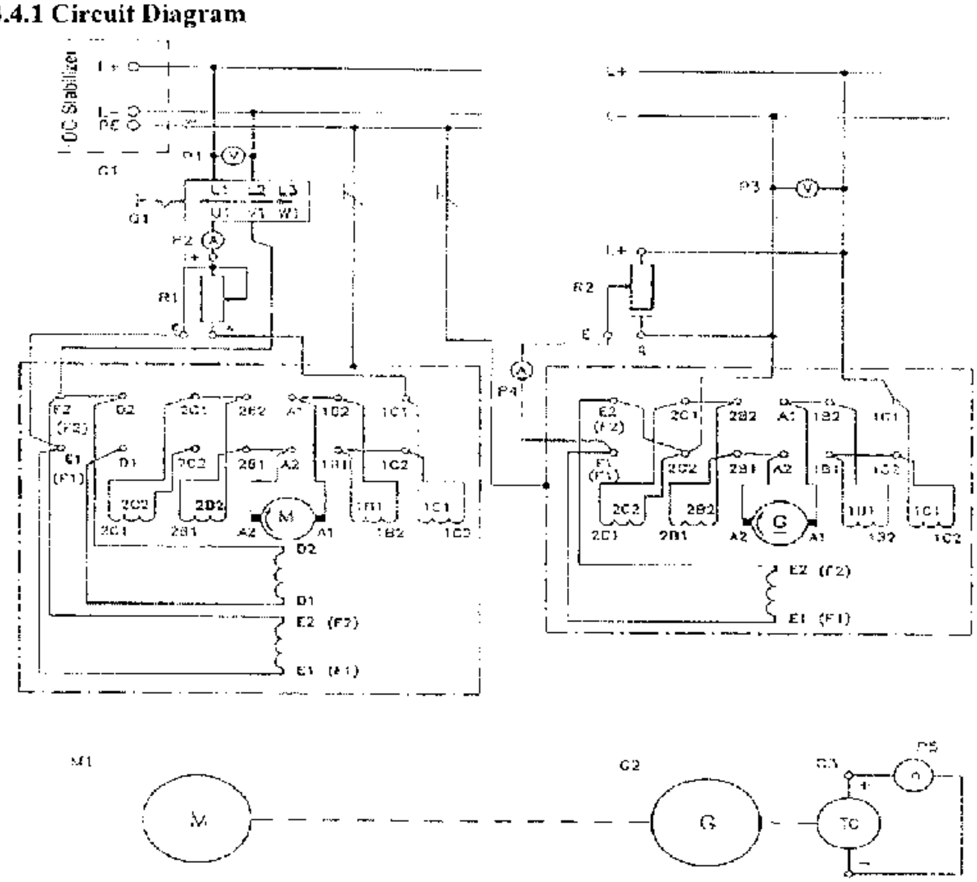
DC Shunt Wound Generator 1.0 - Separately-Excited											
Setting with Voltage supply G_2, I_E = 300 mA, Constant											
Setting the Speed by Reducing the Voltage at G_1 by changing the Resistance R_1											
n (rpm)	2000	1900	1800	1600	1400	1200	1000	900	800	600	500
U_0 (V)											

3.3.3.2 Plot of the No- load Characteristics at constant excitation current I_E

Using the measured values of U_0 (V), and n (min^{-1})), draw the no-load characteristics of the separately –excited DC Shunt wound generator for a constant value of I_E.

3.4 Recording the No-load Characteristic $U0 = f(I_F)$ for Self-excited DC Shunt Wound Generator

3.4.1 Circuit Diagram



3.4.2 Circuit Assembly
Connect the motor M_1 with generator G_2 and tachogenerator G_3. Connect the DC compound wound machine as the driving motor and the DC shunt wound machine as generator for clockwise rotation as specified in the circuit diagram. Assemble the circuit.

3.4.3 Experiment Procedure
After the teacher has checked and approved the circuit, put the circuit into operation. Set the field regulator R_2 to position "q".
Switch on the DC compound wound motor using switch Q_1. Vary the value of the resistance on the starter R_1, so that the speed of 2000^{-1} is indicated on the speed display P_6. If necessary reduce the voltage on the voltage supply G_1. Keep this speed constant while determining the desired measurement values. By changing the resistance values on the field regulator R_2 set predetermined exciter current values I_E at the measurement instrument P_4 as specified in the values table and read off the generator U_0 at the measurement instrument P_1. Enter the determined values in the following tables.

3.4.4 Result Tables
3.4.4.1

DC Shunt Wound Generator 1.0, Self-Excited n (min^{-1}) = 2000 Constant										
Setting on the field Regulator R2 I_E (mA)	0	25	50	75	100	125	150	200	250	300
Measurement U_0 (V)										

3.4.4.2 Plot of the No-load Characteristics $U_0 = f(I_E)$ with $n = 2000\ min^{-1}$ constant
Using the measured values of U_0 and I_E, plot the no-load characteristics of the self-excited DC Shunt Wound generator for a constant speed.

3.5 Recording the No-load Characteristic $U_0 = f(n)$ for Self-Excited DC Shunt Wound Generator

3.5.1 Circuit Diagram
The circuit from 3.5.1 is used

3.5.2 Experiment Procedure
After the teacher has checked and approved the circuit, put the circuit into operation. Set the field regulator R_2 to position "q".
Switch on the DC compound wound motor using switch Q_1. Vary the speed in accordance with the tables by reducing the voltage on the voltage supply G_1 or by changing the resistance value on the starter R_1. Determine the speed on the speed display P_5. At a speed of 2000 min^{-1} set the field regulator R_3 to the highest exciter current value of 0.3 A at the measurement instrument P_4 and keep this setting constant while determining the desired measurement values.

For this measure the desired values of the generator voltage U_0 at measurement instrument P_3 as well as the exciter current values I_E at measurement instrument P_4. Enter these values into the tables below.

3.5.3 Results Table

3.5.3.1

DC Shunt Wound Generator 1.0, Self-Excited											
Setting the field regulator R_3 to the largest exciter current value I_E = 0.3 A for 2000 min^{-1} – Do not change setting, keep constant											
Setting by reducing voltage on G_1 Setting by changing resistance on R_1											
n (rpm)	2000	1900	1800	1700	1600	1500	1400	1300	1200	1200	1000
U0 (V)											
I_E (mA)											

3.5.3.2 Plot of the No-load Characteristics $U_0 = f(n)$ and $I_E = f(n)$

Using the measured values of U_0, I_E, and n of the above table to plot in one graph the No-load characteristics of the Self-excited DC Shunt Wound Generator, Uo against n and I_E against n.

3.6 Load Characteristics U_{KL}, $P_2 = f(I)$ for Separately and Self-Excited DC Shunt Wound Generator

3.6.1 Theory

The terminal voltage available at the terminals of the loaded generator is calculated as follows:

$$U_{KL} = U_0 - I_A (R_A + R_W + R_K)$$

with

$$Ri = R_A + R_W + R_K$$

the result is

$$U_{KL} = U_0 - I_A . Ri$$

U_{KL} = Terminal voltage
U_0 = Electromotive force
I_A = Load or armature current
R_A = Resistance of the armature winding
R_W = Resistance of the commutating winding
R_K = Resistance of the compensation winding

In the case of the self-excited DC Shunt Wound generator this exciter current is a component of the armature current and amount to about 2% to 6% of it:

$I_A = I + I_E$

I = load current
I_A = armature current
I_E = exciter current

Here the armature current is larger than in the separately excited generator by the amount of the exciter current.
In the formula for the terminal voltage
the result is

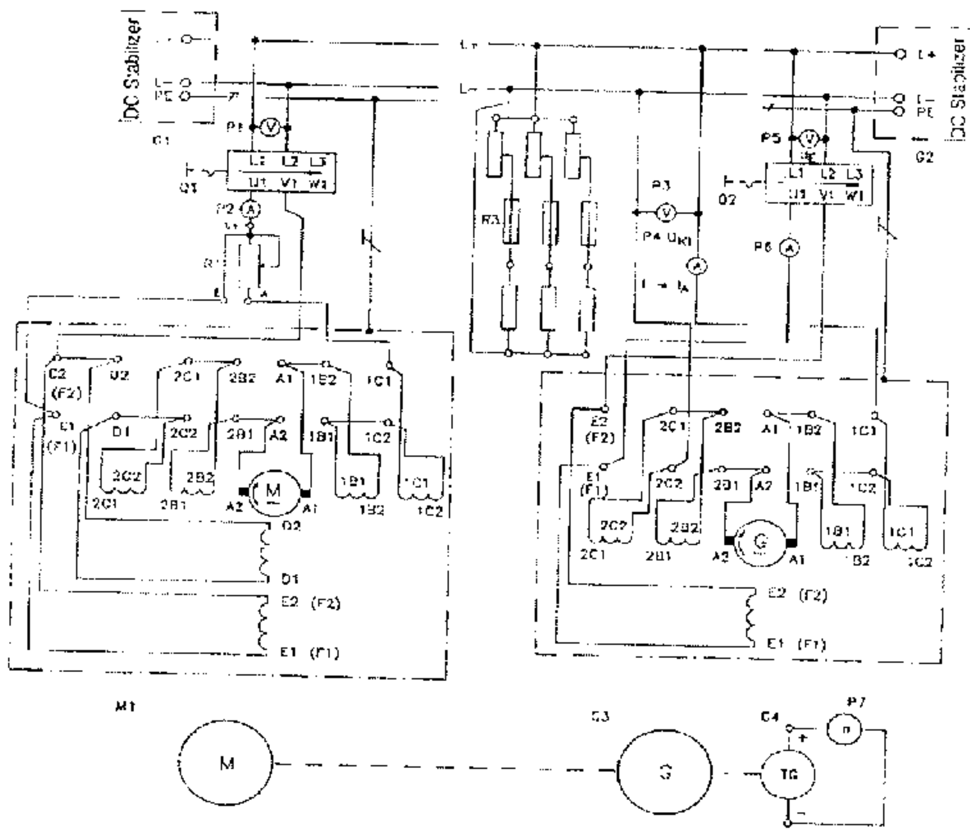
$$U_{KL} = U_0 - I_A . Ri$$

The internal voltage drop

$$Ui = I_A . Ri$$

3.6.2 Load Characteristic U_{KL}, $P_2 = f(I_A)$ for Separately-Excited DC Shunt Wound Generator

3.6.2.1 Circuit Diagram



3.6.2.2 Circuit Assembly

Connect the motor M_1 with generator G_3 and tachogenerator G_4. Connect the DC compound wound machine as the driving motor and the DC shunt wound machine as generator for clockwise rotation as specified in the circuit diagram. Assemble the circuit according to the circuit diagram.

3.6.2.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Switch on the DC compound wound motor using switch Q_1. Set the speed to 2000 min^{-1} using starter R_1 and keep the speed constant for the duration of the measurements.
If necessary the nominal voltage of the motor may be exceeded by 10% by making the corresponding setting on the voltage supply G_1.
Using switch Q_2 connect the exciter voltage of the DC shunt wound generator of the voltage supply G_2. Vary the exciter voltage and subsequently the exciter current to a value of $I_E = 0.3$ A, i.e. to the nominal exciter current for the generator on measurement instrument P_6-, and keep this value constant for the duration of the experiment.
Determine the generator voltage U_{KL} at measurement instrument P_3, for the predetermined armature current values I_A at meter P_4, which result from the setting on the resistor R_3.
Enter the determined values in the following table. Carry out of the measurements as quickly as possible or allow for short breaks between the individual measurements, as the nominal current of the drive motor is partially severely exceeded and the motor wound otherwise reach impermissibly high temperatures.

3.6.2.4 Result Tables

3.6.2.4.1

DC Shunt Wound Generator 1.0-Separately-Excited										
Setting with Starter R_1, $n = 2000\ min^{-1}$ – Constant										
Setting with Voltage Supply G_2, $I_E = 0.3$ A -Constant										
Setting with Load Resistor R_3										
I_A (A)	0.6	0.8	1.0	1.25	1.75	2.0	2.25	2.5	2.75	3
Measurement U_{KL} (V)										
Calculation P_2 (W)										

3.6.2.5 Calculation

Calculate the power output P_2 for the table above from the following equation:

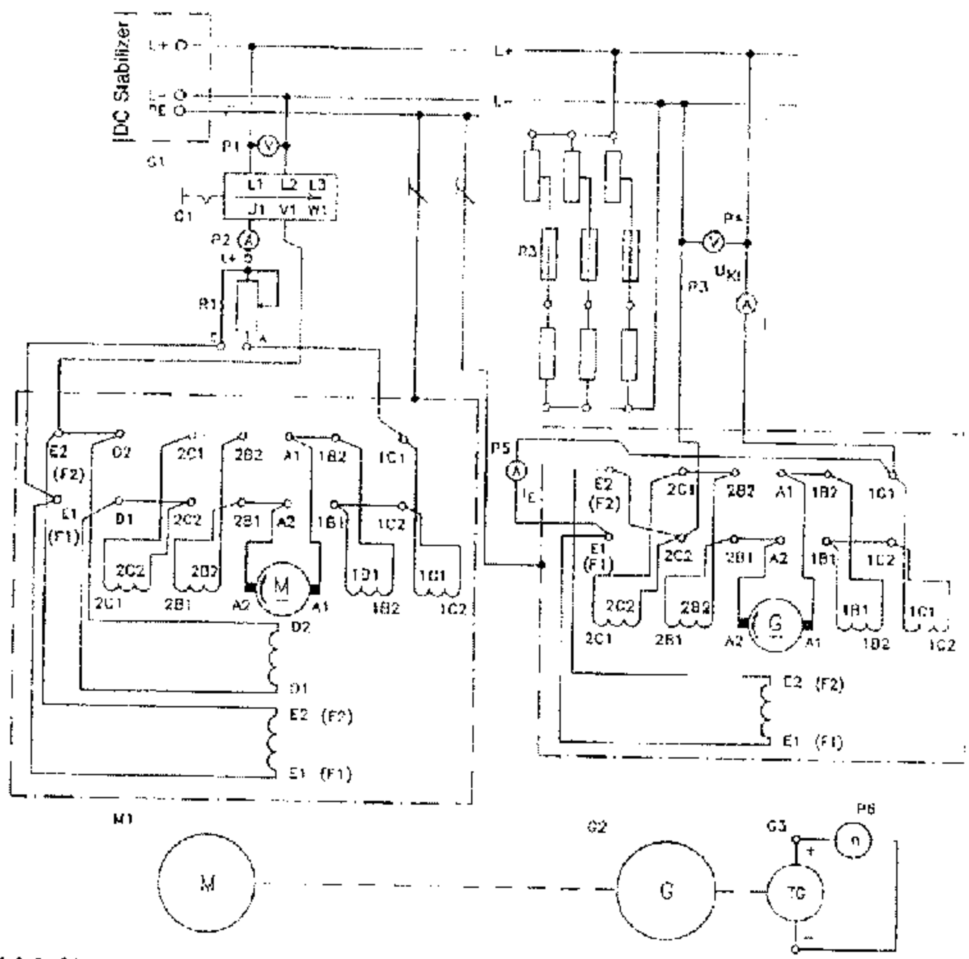
$$P_2 = U_{KL} \cdot I_A$$

3.6.2.6 Plot of the Load Characteristics U_{KL}, $P_2 = f(I_A)$ at n, I_E = Constant for Separately-excited DC Shunt Wound Generator

Using the measured values of U_{KL} and the calculated values of P_2 and plot the load characteristics as a function of I_A at constant values of n and I_E.

3.6.3 Load Characteristic U_{KL}, $P_2 = f(I_A)$ for Self-Excited DC Shunt Wound Generator

3.6.3.1 Circuit Diagram



3.6.3.2 Circuit Assembly

Connect the motor M_1 with generator G_2 and tachogenerator G_3. Connect the DC compound wound machine as the driving motor and the DC shunt wound machine as generator for clockwise rotation as specified in the circuit diagram. Assemble the circuit according to the circuit diagram.

3.6.3.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Switch on the DC compound wound motor using switch Q_1. Set the speed to 2000 min^{-1} using starter R_1 and keep the speed constant for the duration of the measurements.
If necessary the nominal voltage of the motor may be exceeded by 10% by making the corresponding setting on the voltage supply G_1.

Determine the generator voltage U_{KL} at measurement instrument P_4 as well as the excited current I_E at measurement instrument P_5 for the predetermined armature current values I_A at meter P_3, which result from the setting on the resistor R_3.
Enter the determined values in the following table. Carry out of the measurements as quickly as possible or allow for short breaks between the individual measurements, as the nominal current of the drive motor is partially severely exceeded and it would otherwise reach impermissibly high temperatures.

3.6.3.4 Result Tables

3.6.3.4.1

DC Shunt Wound Generator 1.0 - Self-Excited										
Setting with Starter R_1, $n = 2000\ min^{-1}$ - Constant										
Setting with Load Resistor R_3										
I_A (A)	0.6	0.8	1	1.2	1.4	1.6	1.8	2	.....	3.6
Measurement U_{KL} (V)										
Measurement I_E (mA)										
Calculation P_2 (W)										

3.6.3.5 Calculation

Calculate the power output P_2 for the table above from the following equation:

$$P_2 = U_{KL} \cdot I_A$$

3.6.3.6 Plot of the Load Characteristics U_{KL}, P_2, $I_E = f(I_A)$ at n = Constant for Self-Excited DC Shunt Wound Generator

Using the measured values of U_{KL}, I_E and the calculated values of P_2 and plot the load characteristics as a function of I_A at constant values of n.

3.7 Load Characteristics U_{KL}, $P_2 = f(I)$ for Separately and Self - Excited DC Compound Wound Generator

3.7.1 Theory

The terminal voltage available at the terminals of the loaded generator is calculated as follows:

$$U_{KL} = U_0 - I_A (R_A + R_W + R_K + R_{EH})$$

with

$$Ri = R_A + R_W + R_K + R_{EH}$$

the result is

$$U_{KL} = U_0 - I_A \cdot Ri$$

U_{KL} = Terminal voltage
U_0 = Electromotive force
I_A = Load or armature current
R_A = Resistance of the armature winding

R_W = Resistance of the commutating winding
R_K = Resistance of the compensation winding
R_{EH} = Resistance of the series wound exciter winding

In this generator the shunt wound exciter winding is connected parallel to the armature circuit. The field regulator is positioned in series to the exciter winding in order to set the exciter current in the shunt wound exciter winding.
In the case of the DC compound wound generator, this shunt wound exciter current is a component of the armature current and amount to about 2% to 6% of it:

$I_A = I + I_E$

I = load current
I_A = armature current
I_E = exciter current

Here the armature current is larger than in the separately excited generator by the amount of the exciter current.
In the formula for the terminal voltage
the result is

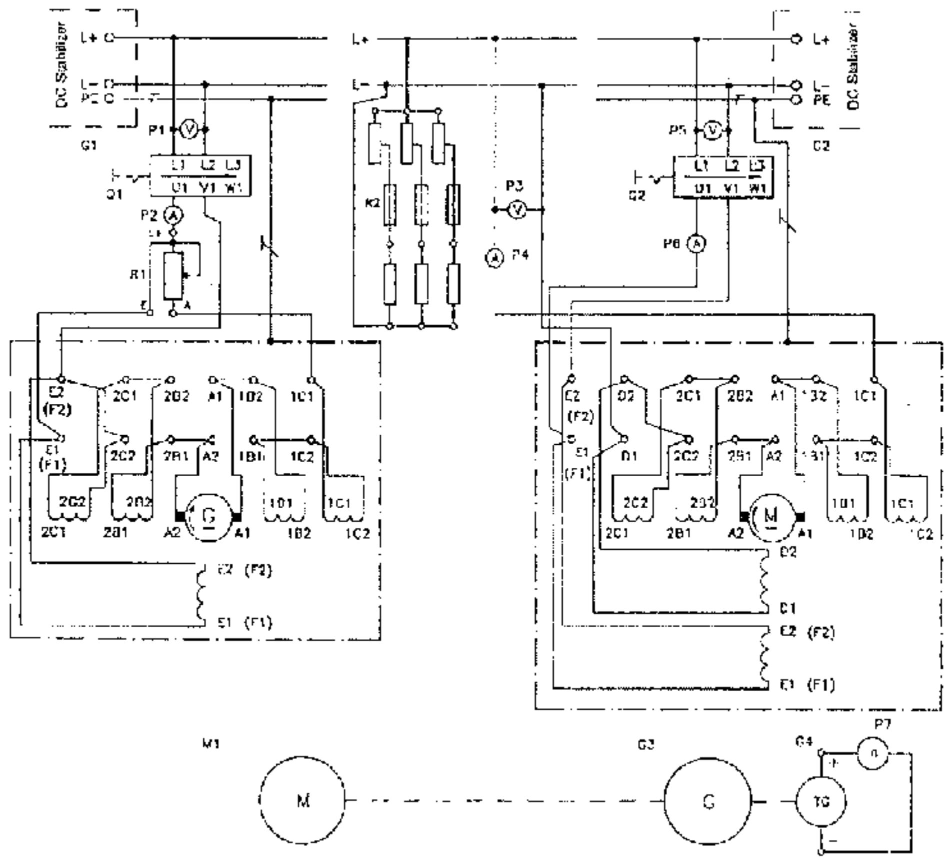
$$\mathbf{U_{KL} = U_0 - I_A . Ri}$$

The internal voltage drop

$$\mathbf{Ui = I_A . Ri}$$

3.7.2 Load Characteristics U_{KL}, $P_2 = f(I_A)$ for Separately-Excited Compound Wound Generator

3.7.2.1 Circuit Diagram



3.7.2.2 Circuit Assembly

Connect the motor M_1 with generator G_3 and tachogenerator G_4. Connect the DC shunt wound machine as the driving motor and the DC shunt wound machine as generator for clockwise rotation as specified in the circuit diagram. Assemble the circuit according to the circuit diagram.

3.7.2.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Switch on the DC compound wound motor using switch Q_1 and set the speed to 2000 min^{-1}

- by varying the resistance value on the starter R_1
- by varying the voltage from the voltage supply

and keep this value of speed constant for the duration of the measurements.
Using switch Q_2 switch on the exciter voltage of the DC compound wound generator from the voltage supply G_2.
Vary the exciter voltage and subsequently the exciter-current-measurement instrument P_6 – to a value I_E = 0.30 a, which corresponds to the generator nominal exciter current and keep this value constant for the duration of the measurements. Determine the generator

voltage U_{KL} at measurement instrument P3, for the given armature current values I_A at measurement instrument P_4, which result from setting at load resistor R_2.
Enter the determined values into the tables below.
Conduct the measurements as quickly as possible or provide for short breaks between the individual measurements, as the nominal current of the drive motor can be considerably exceeded at times and it would otherwise reach impermissibly high temperatures.

3.7.2.4 Result Tables

3.7.2.4.1

DC Compound Wound Generator 1.0-Separately -Excited									
Setting with Starter R_1, $n = 2000\ min^{-1}$ – Constant **Setting with the voltage Supply G_1**									
Setting with the Voltage Supply G_2 $I_E = 0.30$ A - Constant									
Setting with load resistor R_2									
I_A (A)	0.6	0.8	1	1.2	1.4	1.6	1.8	2	......	3.6
Measurement U_{KL} (V)										
Calculation P_2 (W)										

3.7.2.5 Calculation

Calculate the power output P_2 for the table above from the following equation:

$$P_2 = U_{KL} \cdot I_A$$

3.7.2.6 Plot the Load Characteristics U_{KL}, $P_2 = f(I_A)$ with n, I_E = Constant for Separately - Excited DC Compound Wound Generator

Using the measured values of U_{KL} and the calculated values of P_2 and plot the load characteristics for Separately-excited DC as a function and for constant values of n and I_E.

Experiment # 5: Multi-Function DC Machine as a Shunt, Series and Compound Wound Motor

1. Objectives: To study the following for the multi-function DC machine operates as a shunt, series and compound wound motor:

- Recording and Plotting the Load Characteristics of the machine as shunt wound motor $\mathbf{n, I_A, \eta, P_1, P_2 = f(M)}$
- Speed-Exciter Current Characteristics $\mathbf{M = f(I_E)}$ and
- Speed-Armature Voltage Characteristics $\mathbf{M = f(U_A)}$
- Recording and Plotting the Load Characteristics of the machine as series wound motor $\mathbf{n, I_A, \eta, P_1, P_2 = f(M)}$
- Recording and Plotting the Load Characteristics of the machine as compound wound motor $\mathbf{n, I_A, \eta, P_1, P_2 = f(M)}$

2. Experiment components and measurement instruments:

- DC Stabilizer
- On/off Switch Three Pole
- Multi-function machine
- Armature series resistor
- Control unit
- Magnetic powder brake
- Tacho generator
- RMS meters

3 Load Characteristics of a Multi-function DC Machine as Shunt Wound Motor $\mathbf{n, I_A, \eta, P_1, P_2 = f(M)}$

3.1 Theory:

The torque is proportional to the magnetic field and the armature current:

$$\mathbf{M \sim \phi I_A}$$

The induction voltage is dependent on the magnetic field and the speed of the armature:

$$\mathbf{Uo \sim \phi n}$$

For the speed the equation can be restated:

$$\mathbf{n \sim Uo / \phi}$$

Instead of the back emf Uo, the difference between the terminal voltage U_{KL} and the voltage drop across the armature can be used

$$\mathbf{n \sim (U_{KL} - I_A \cdot Ri) / \phi}$$

The voltage drop $\mathbf{I_A \cdot Ri}$ between no-load and load, at constant terminal voltage, represents a small value.

The consumed power P_1 is calculated from the measured values for U, I_A and I_E.

$$\mathbf{P_1 = U (I_A + I_E)}$$

If the torque M and the speed n have been determined for various loads, the corresponding motor power P_2 delivered can be determined

$$P_2 = M \cdot \omega$$

P_2 – delivered power in watt

M = torque in Nm

ω = angular velocity, S^{-1}

The following relationship exists between angular velocity and rotor speed n:

Formula: $\omega = 2\,\pi\, n / 60$

$\omega = 2\,\pi\, n / 60$

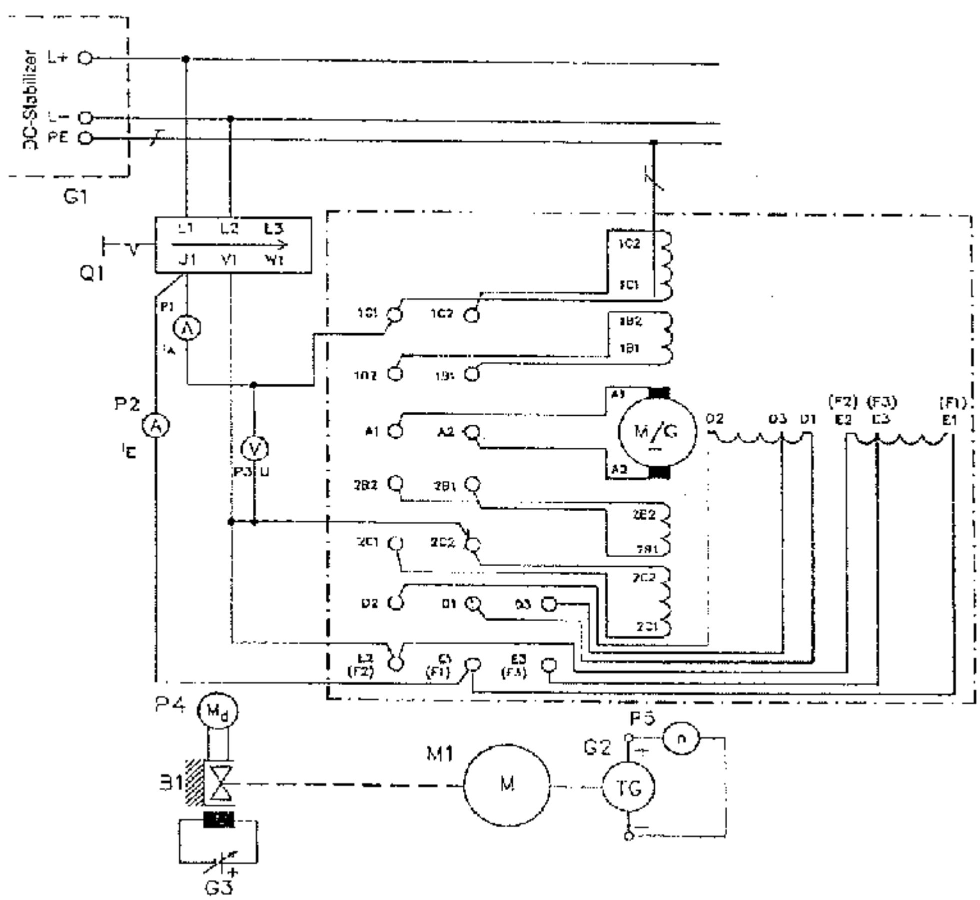
$\omega = n / 9.55$

Therefore $P_2 = M \cdot n / 9.55$

The efficiency is given by the ratio between delivered power and consumed power.

$$\eta = P_2 / P_1$$

3.2 Circuit Diagram



3.3 Circuit Assembly
Make the appropriate connections on the multi-function machine as DC shunt wound motor according to the circuit diagram. Assemble the circuit.

3.4 Experiment Procedure
After the teacher has checked and approved the circuit, put the circuit into operation.
Load the motor between no-load operation and two times the nominal torque.
Measure the speed n, the armature current I_A, the exciter current I_E under load in accordance with the values given in the table.

Setting the Magnetic Powder Brake on the Control Unit
Before operation set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min⁻¹"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

Put the motor into operation.
Conduct this experiment as quickly as possible because under load the nominal current of the motor is exceeded and thus the motor is temporarily highly overloaded which leads to the deactivation of the braking action via the thermal switch.

3.5 Result Table
Enter the measured and calculated values into the following results table!

3.5.1 **Results Table**

Multi function Machine as DC Shunt Wound Motor 1.0									
	M/Nm	0.4	1	1.5	2	2.5	3	3.5	4
Measurement	n/min^{-1}								
	I_A/A								
	I_E/A								
Calculation	I_{tot}/A								
	P_1/W								
	P_2/W								
	η								

3.6 Calculation:

Calculate the desired values required for completing the results table and enter them into the table. Show the calculation steps for measurement at load with nominal torque. Use the appropriate values from the table above and using the following relationships:

$\mathbf{I_{tot} = I_A + I_E}$

$\mathbf{P_1 = U \cdot I_{tot}}$

$\mathbf{P2 = M \cdot n / 9.55}$

$\eta = \mathbf{P_2 / P_1}$

3.7 Load Characteristics

Using the measured and the calculated values, plot the curves for the multi-function machine as DC shunt wound motor. Draw the nominal torque in the diagram as a perpendicular line

4. Multi-function Machine as DC Shunt Wound Motor

- **Speed-Exciter Current Characteristics $\mathbf{n = f(I_E)}$ and**
- **Speed-Armature Voltage Characteristics $\mathbf{n = f(U_A)}$**

4.1 Theory:

The following is true for the DC shunt wound motor

$\mathbf{I_A = (U_{KL} - U_o) / R_i}$ I_A = Armature Current
U_{KL} = terminal voltage at the armature circuit
U_o = Induced back e.m.f. in the armature
and R_i = Internal resistance(= armature circuit resistance)
n – Speed of the rotor
$\mathbf{Uo = n\phi \cdot C}$ ϕ = Magnetic flux of the exciter field
C = Machine constants (conductor length, number of windings)

The following can be concluded for the speed of the motor:

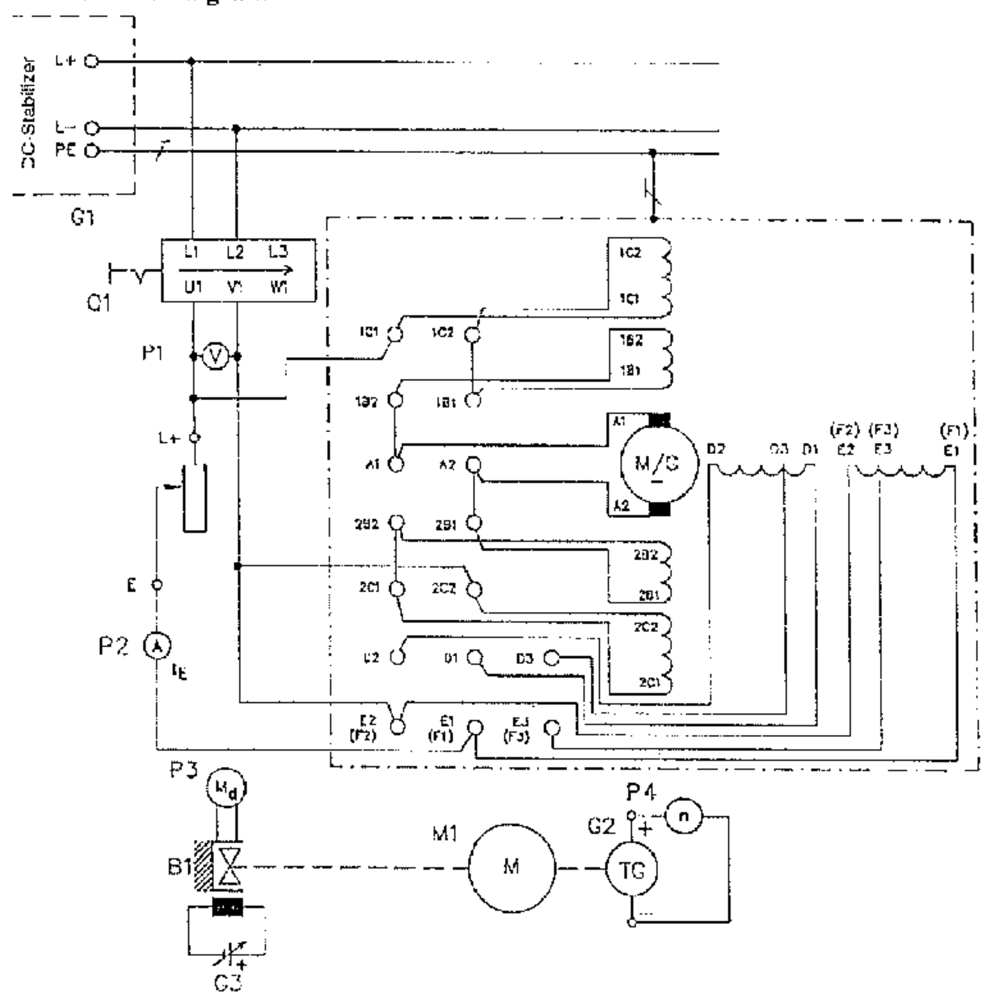
$\mathbf{n = U_o / (\phi.C)}$

$\mathbf{U_o = U_{KL} - I_A.Ri}$ ⇒ When this is substituted for Uo in the equation, the following results:

$\mathbf{n = (U_{KL} - I_A.Ri) / (\phi.C)}$

4. 2 Speed-Exciter Characteristics $n = f(I_E)$

4.2.1 Circuit Diagram



4.2.2 Circuit assembly

Connect the multi-function machine as DC shunt wound motor according to the circuit diagram above. Assemble the circuit!

4.2.3 Experiment Procedure

After the instructor has checked and approved the circuit put the motor into operation. Load the motor with the nominal torque $M_N = 2.2$ Nm. Measure the speed n at each exciter current value I_E according to the values given in the table.

<u>Setting the Magnetic Powder Brake on the Control Unit</u>

Before operation, set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min^{-1}"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

Put the motor into operation

4.2.4 Results Table

Enter the determined values in the table below.

4.2.4.1 Results Table

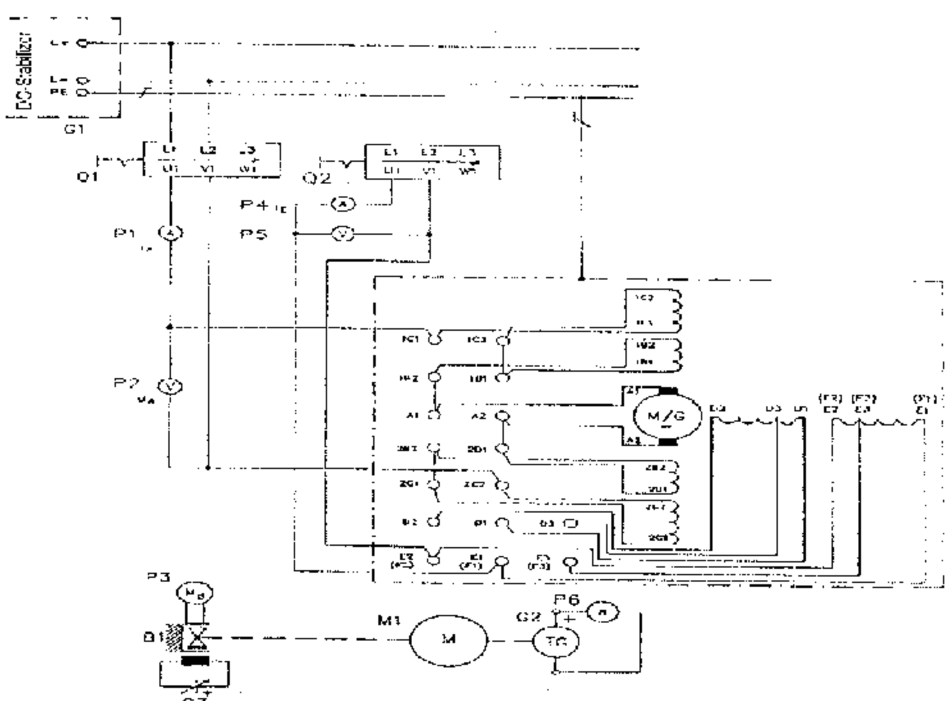
Multi-Function Machine as DC Shunt Wound Motor 1.0						
I_E (mA)	340	320	300	280	260	240
n (rpm)						

4.2.5 Speed-Exciter Characteristics

Plot the measured values of the multi-function machine as DC shunt wound motor in the form of a graph!

4.3 Speed - Armature Voltage Characteristic $n = f(U_A)$

4.3.1 Circuit Diagram



4.3.2 Circuit Assembly
Connect the multi-function machine as DC shunt wound motor according to the circuit diagram above. Assemble the circuit.

4.3.3 Experiment Procedure
After the instructor has checked and approved the circuit put the motor into operation. Load the motor with the nominal torque Mn = 2.2 Nm and set the nominal exciter current value to I_E = 300 mA and measure the speed n at various armature voltage U_A according to the values given in the table. By measuring the initial and final values, determine also the behavior of the armature current.

<u>**Setting the Magnetic Powder Brake on the Control Unit**</u>
Before operation, set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min^{-1}"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

Put the motor into operation. Make sure that nominal torque is always maintained during the measurements.

4.3. 4 Results Table
Enter the determined values in the table below.

4.3.4.1 <u>Results Table</u>

Multi-function Machine as DC Shunt Wound Motor 1.0										
U_A/V	220	200	180	160	140	120	100	80	60	40
n/min⁻¹										
I_A/V										

4.3.5 Speed-Armature Voltage Characteristics
Plot the measured values of the multi-function machine as DC shunt wound motor in a form of a graph!

5. Load Characteristics of a Multi-Function DC Machine as Series Wound Motor $n, I_A, \eta, P_1, P_2 = f(M)$

5.1 Theory:
The torque is proportional to the magnetic field and the armature current:

$$M \sim \phi \cdot I_A$$

The induction voltage is dependent on the magnetic field and the speed on the armature:

$$\mathbf{U_o \sim \phi \cdot n}$$

For the speed the equation can be restated:

$$\mathbf{n \sim U_o / \phi}$$

For the DC series wound motor, the exciter winding is connected in series to the armature, thus the magnetic flux ϕ of the exciter field is formed by the armature current; or: $\phi \sim I_A$

Thus the torque becomes

$$\mathbf{M \sim I_A \cdot I_A} \text{ ; or}$$

$$\mathbf{M \sim I_A^2}$$

As a result the DC series wound motor reaches at starting and at low speeds especially high torques.

The consumed power P1 is calculated from the measured values for U, IA.

$$\mathbf{P_1 = U \cdot I_A}$$

If the torque M and the speed n have been determined for various loads, the corresponding motor power P_2 delivered can be determined.

$$\mathbf{P_2 = M \cdot \omega}$$

Since;

$$\omega = \mathbf{2\,\pi\,n / 60}$$

$$= \mathbf{n / 9.55}$$

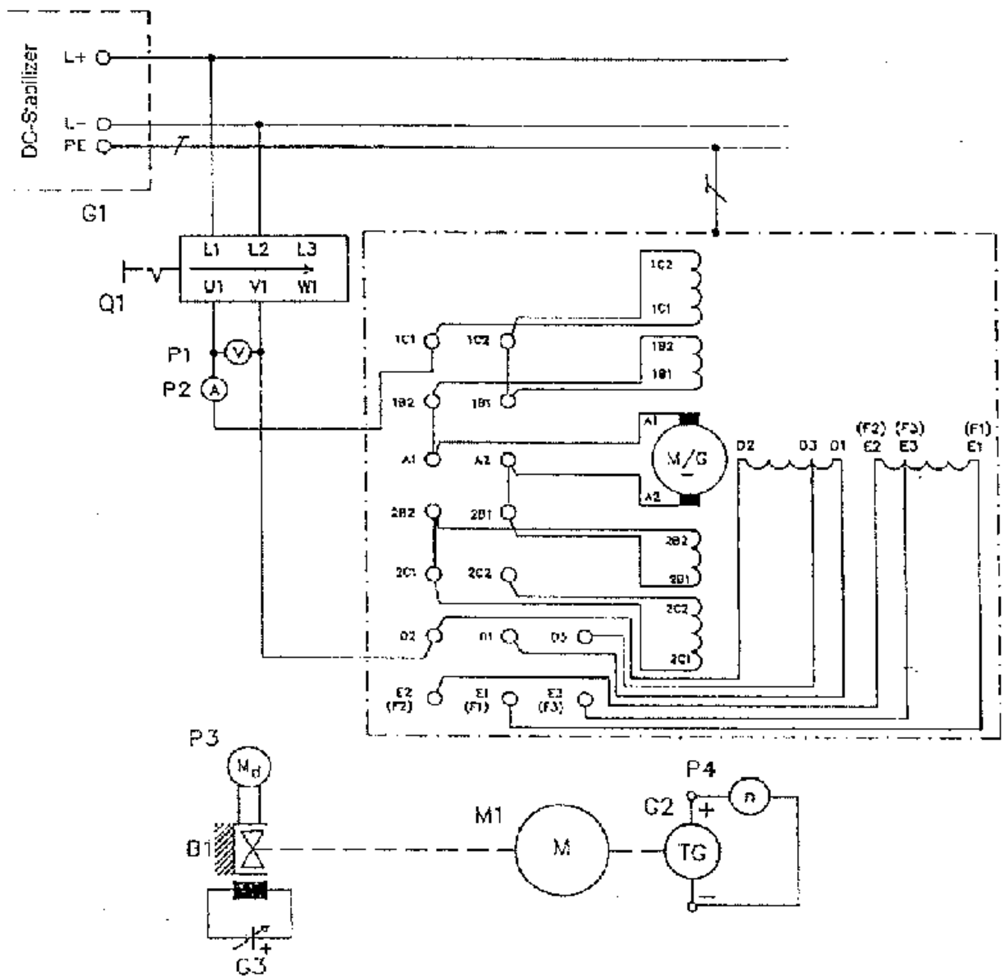
Therefore;

$$\mathbf{P_2 = M \cdot n / 9.55}$$

The efficiency is given by the ratio between delivered power and consumed power.

$$\eta = \mathbf{P_2 / P_1}$$

5.2Circuit Diagram



5.3Circuit Assembly

Making the appropriate connections on the multi-function machine as DC series wound motor according to the circuit diagram. Assemble the circuit.

5.4 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Load the motor between no-load operation (residual friction) and two times the nominal torque as specified in the tables. Measure the speed n, the armature current I_A at a DC voltage of 220 V.

Setting the Magnetic Powder Brake on the Control Unit

Before operation set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min^{-1}"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

Put the motor into operation.
Conduct this experiment as quickly as possible because under load the nominal current of the motor is exceeded and thus the motor is temporarily highly overloaded which leads to the deactivation of the braking action via the thermal switch.
Make sure that the operating mode switch of the control unit is only briefly set to "0" then immediately switch over to "MAN1". Thus the residual friction of the brake prevents the DC series wound motor from "racing".

5.5 Results Table
Enter the measured and calculated values into the following results table!

5.5.1 Results Table

Multi-function Machine as DC Series Wound Motor 1.0									
Measurement	M/Nm	1.0	1.5	2.0	2.5	3.0	3.6	4.0	4.5
	n/min^{-1}								
	I_A/A								
Calculation	P_1/W								
	P_2/W								
	η								

5.6 Load Characteristics
Using the measured and calculated values; plot the curves for the multi-function DC machine as series wound motor in a graph. Draw a vertical line for the nominal torque on the diagram.

6. Multi-function Machine as DC Compound Wound Motor

- **Load Characteristics n, I_A, η, P_1, P_2 = f (M), with normal compound**

6.1 Theory:
In standard compound motors, the series wound exciter winding is connected so that its magnetic field has the same direction as the magnetic field of the shunt winding. At no-load the compound motor behaves like a shunt wound motor. Under load the speed of the compound motor decrease somewhat more severely since the main magnetic flux also becomes greater on account of the stronger armature current.
Under load conditions, he consumed power P1 is calculated from the measured values for U, I_A, and I_E

$$P_1 = U\ (IA + I_E)$$

If the torque M and the speed n have been determined for various loads, the corresponding motor power P_2 delivered can be determined.

$$P_2 = M\ .\ \omega$$

Since;

$$\omega = 2\ \pi\ n\ /\ 60$$
$$= n\ /\ 9.55$$

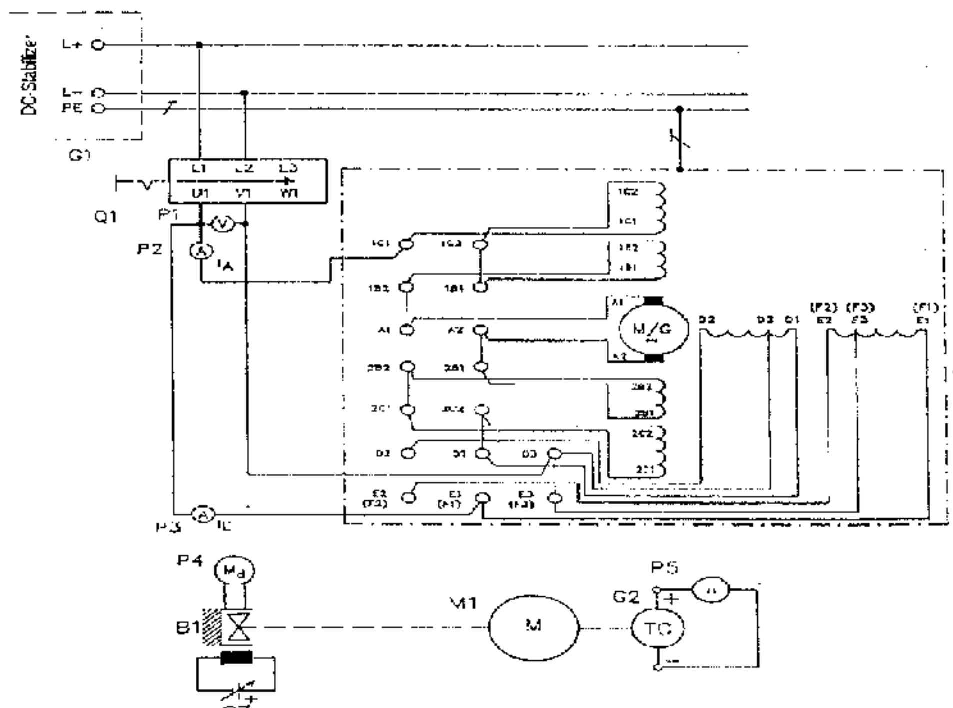
Therefore;

$$P_2 = M\ .\ n\ /\ 9.55$$

The efficiency is given by the ratio between delivered power and consumed power.

$$\eta = P_2\ /\ P_1$$

6.2 Circuit Diagram



6.3 Circuit assembly

Making the appropriate connections on the multi-function machine as DC compound wound motor according to the circuit diagram. Assemble the circuit.

6.4 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Load the motor between no-load operation (residual friction, from the brake) and two times the nominal torque as specified in the tables. Measure the speed n, the armature current I_A, the exciter current I_E at a DC voltage of 220 V.

Setting the Magnetic Powder Brake on the Control Unit
Before operation set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min^{-1}"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

Put the motor into operation.
Conduct this experiment as quickly as possible because under load the nominal current of the motor is exceeded and thus the motor is temporarily highly overloaded which leads to the deactivation of the braking action via the thermal switch.

6.5 Results Table
Enter the measured and calculated values into the following results table!

6.5.1 Results Table

Multi-function Machine as DC Compound Wound Motor 1.0									
	M/Nm	0.5	1	1.5	2	2.5	3	3.5	3.6
Measurement	n/min^{-1}								
	I_A/A								
	I_E/A								
Calculation	I_{tot}/A								
	P_1/W								
	P_2/W								
	η								

6.6 Calculation
Calculate the desired values required for completing the results table using the following relationships, and enter them into the table! Show the calculation steps for measurement at load with nominal torque. Use the appropriate values from the table above.

$$M_N = P_{2N} \cdot 9.55 / n_N$$
$$I_{tot} = I_A + I_E$$
$$P_1 = U \cdot I_{tot}$$
$$P_2 = M \cdot n / 9.55$$

$\eta = P_2 / P_1$

6.7 Load Characteristics

Using the measured and calculated values, plot the curves for the DC compound wound motor in a graph. Draw a vertical line for the nominal torque on the diagram.

Experiment # 6: Multi-Function Machine as Three-phase Synchronous Generator

1. Objectives:

- To be familiar with the performance of a synchronous generator under no-load by measuring the exciter current and the corresponding stator voltage at various speeds
- Determine the no-load nominal exciter current from the measured values.
- To become familiar with the performance of a synchronous generator with short-circuited stator winging by measuring the exciter current and corresponding stator current at various speed.
- Determining the no-load short - circuit current and the quantities which can be derived from it.
- To become familiar with the performance of a synchronous generator operating with the excitation and speed kept constant under different kinds of load.
- To become familiar with various lamp circuits and other aids for synchronization used to connect a synchronous generator in parallel to a constant-voltage constant-frequency system.

2. Equipments:

- Three-phase Supply
- DC voltage source
- On / Off Switches three-phase
- Tacho Generator
- Multi-function Machine
- DC machine
- Power Factor Meter
- RMS Meters
- Power Meter
- Double voltmeter
- Double frequency meter
- Synchronoscope
- Synchronization indicator
- Phase-sequence indicator

3. No-Load Characteristics of a Synchronous Generator

3.1 Theory

The expression for the induced phase voltage E_{rms} of a three-phase synchronous generator is written as:

$$E_{rms} = 4.44\ K_w\ f\ Na\ \Phi_p \qquad (1)$$

K_w – machine stator winding factor
f = frequency
N_s = stator winding number of turns per phase

Φ_p = flux per pole.

The relationship described by Eq. (1) is referred to as the magnetization curve, or saturation curve, or open-circuit characteristic (OCC) of a synchronous machine.

3. 2 Circuit Diagram

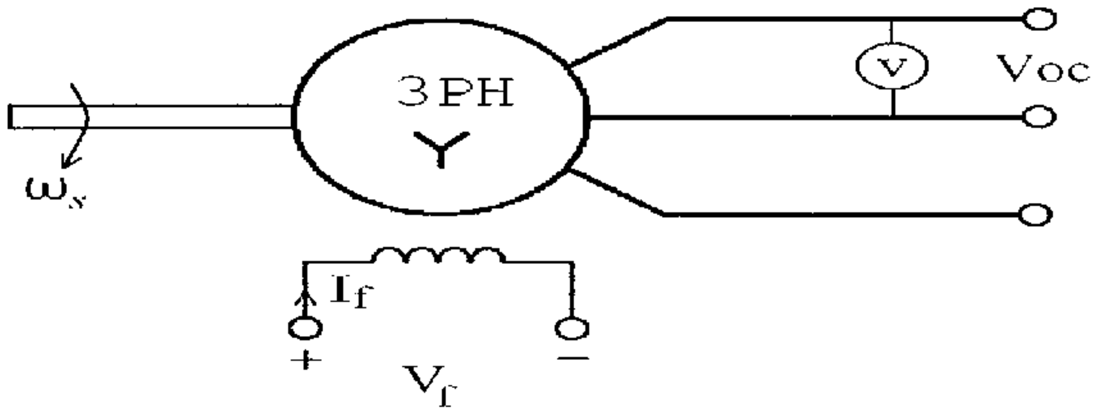


Figure 1 : Circuit connectionn for No-Load characteristics.

3.3 Circuit Assembly

Assemble the measurement circuits according to the above circuit diagram.

3.4 Experiment Procedure

After the circuit set-up has been completed and checked, the DC motor – AC synchronous generator set is to be put into operation as follows:

1. Adjust the DC motor speed to three different constant speeds as shown in the following tables. One of the speeds must be equal to the synchronous speed of the synchronous generator.
2. Vary the exciter current in steps as shown by varying the variable DC voltage supply.
3. Record the line-to-line voltage Us and the exciter current I_E. Make sure that the speed remains constant through the whole test.
4. For n = 1800 rpm, Synchronous speed, take readings up to 110% of the rated voltage of the generator.
5. Put the results in the following tables

3.5 Result Table

Enter the measured values in the following tables

3.5.1

Set DC motor speed to n = 1800 min^{-1} constant (Synchronous speed)								
I_E (A)	0	0.5	1	1.5	2	2.5	3.2	4.3
Us (V)								

3.6 No- load Characteristic plots

Plot the voltage curves for the three speeds as a function of the exciter currents in a joint diagram and compare the curves with the statements made in the theoretical section

4. Short-Circuit Characteristic of a Synchronous Generator

4.1 Theory

If readings of a short-circuit current are taken and plotted for different values of field current, the plot described is called the short-circuit characteristic (SCC) of the synchronous machine. A typical SCC is linear.

4.2 Circuit Diagram

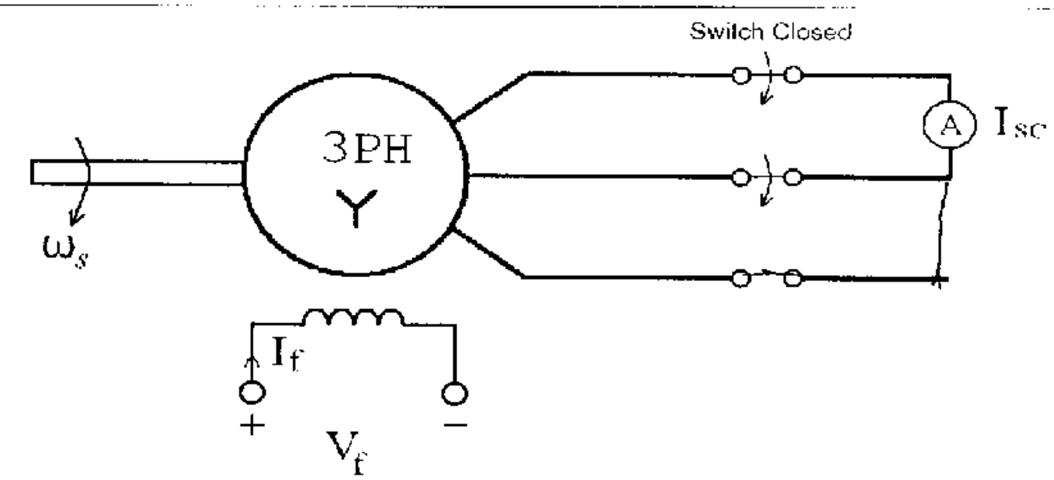


Figure 2 : Circuit connectionn for short-circuit characteristics.

4.3 Circuit Assembly

Assemble the measurement circuits according to the above circuit diagram.

4.4 Experiment procedure

1. Stop the DC motor and connect the circuit as shown in the above circuit diagram for the short circuit test of the synchronous generator.
2. After complete and checking the circuit diagram, and with the Synchronous generator exciter off, put the M-G set on and bring the DC motor up to n – 1800 min^{-1} as in the no-load test
3. Close the three-phase switch connected to the three-phase terminals of the generator and gradually increase the exciter current I_E by changing the variable DC voltage source.
4. Record the exciter current I_E and the armature current Ia.
5. Repeat steps 3 and 4 for n = 1800 min^{-1} and n – Synchronous speed.
6. For n = Synchronous speed, take readings up to 120% of the rated generator current.

7. Put the results in the following tables

4.5 Result Tables

Change the field current to obtain the prefixed values for the short armature current. Enter the measured values in the following table

4.5.1

Set DC motor speed to n = 1800 min^{-1} constant (Synchronous speed)					
If (A)					
Ia (A)	0.2	0.4	0.6	0.8	1.0

4.6 Short-Circuit Characteristic plots

Plot the recorded measured values in a joint diagram and compare the curves with the statements made in the theoretical section.

4.7 Calculation of Synchronous Reactance from OCC and SCC, and Voltage Regulation

The open-circuit and short-circuit characteristics of the synchronous machine can be used to determine the value of its synchronous reactance.

From the short-circuit conditions, the stator current Ia, is:

$$I_{a,sc} = E_a / (R_a + jX_s) \tag{2}$$

Where

$$Z_{sc} = (R_a + jX_s) \tag{3}$$

The saturated synchronous reactance can be calculated from the OCC and SCC by taking the rated terminal voltage (line-to-line) measured on the OCC and dividing by the current read from the SCC corresponding to the field current that produces the terminal voltage. Thus,

$$X_{s,sat} = (V_{t,rated} / \sqrt{3}) / I_{a,sc} \tag{4}$$

5. DC Resistance Measurement Test

5.1 Circuit Diagram

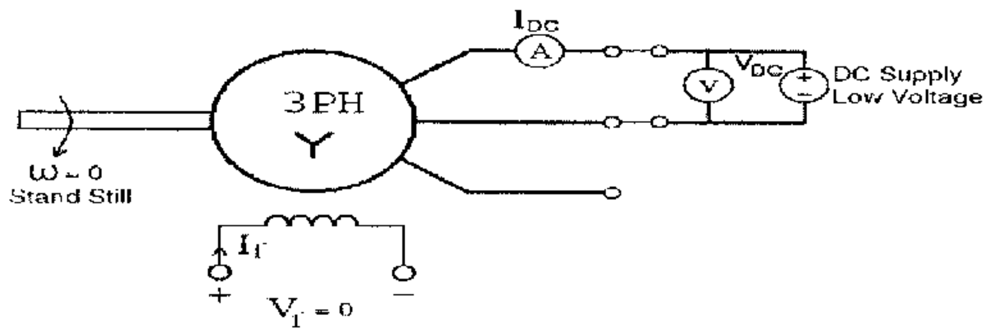


Figure 3 : Volt-Ammeter method for DC resistance Calculation.

5.2 Circuit Assembly

Assemble the measurement circuits according to the above circuit diagram.

5.3 Experiment Procedure

1. Adjust the DC power supply so that the current flowing through the synchronous generator winding does not exceed the rated armature current. The DC resistance is given by:

$$R_{dc} = V_{dc} / 2\, I_{dc} \qquad (5)$$

The armature resistance, Ra can be considered to be 1.5 times R_{dc}, or

$$R_a = 1.5\, R_{dc} \qquad (6)$$

6. Load Characteristics of Synchronous Generator

6.1 Theory

For certain load current Ia, the internal voltage per phase of the generator can be determined by the following equation:

$$E_a = V_t + I_a\,(R_a + jX_s) \qquad (7)$$

The voltage regulation of the generator at rated load conditions is given by:

$$VR\,\% = (V_{nl} - V_{fl}) / V_{fl} \times 100 \qquad (8)$$

Where

$V_{nl} = E_a$: no-load voltage

$V_{fl} = V_t$ (rated): Full-load voltage at rated voltage

6.2 Circuit Diagram

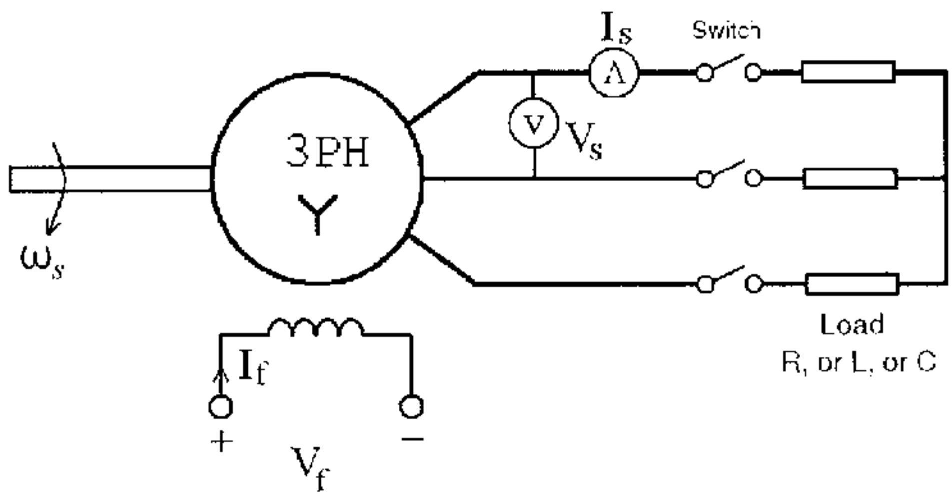


Figure 4 Circuit Connection for Load Characteristics.

6.3 Circuit assembly

Assemble the measurement circuits according to the above circuit diagram.

6.4 Experiment Procedure

- The resistive load will be used first. It is connected like all the other loads in star connection. The load is set to the 100% value before starting the measurements.
- After the machine-generator set has been started and its nominal speed of 1800 min^{-1} has been reached, the nominal exciter current has to be set on the synchronous machine and then maintained for all measurements.
- Beginning from a value of 100% of the resistive load, gradually reduce its resistance level according to the result table below and measure the corresponding stator current and voltage for each value.
- After the de-excitation of the synchronous machine, the resistive load is replaced by the inductive load (also connected in star configuration).
- The above measurement is repeated in the same fashion for the inductive load shown in the result table.
- Bear in mind that a de-excitation for the synchronous machine has to be performed each time before changing the inductive load value. The measurements have to be performed very rapidly as otherwise the inductive load could be overloaded.
- Repeat the above measurements for the capacitive load (again in star connection) using the capacitive load values shown in the result table.

6.5 Result tables

Enter the measured values in the following tables

6.5.1

R %	100	80	60	45	20	10	8
Is (A)							
Us (V)							
P(W)							

6.5.2

L (H)	4.8	2.4	1.2	1.0
Is (A)				
Us (V)				
P(W)				

6.5.3

C (μF)	2	4	8	16
Is (A)				
Us (V)				
P(W)				

6.6 Load Characteristics of a Synchronous Generator

Plot the measured stator voltages as a function of the stator current for all three load types in a joint diagram.

6. 7 Calculation of the Voltage Regulation

1. Using the OCC and SCC plots for the n = synchronous speed to calculate Zs and Xs using equations (2 - 4).

2. Calculate analytically, the voltage regulation of the synchronous generator for the following loading conditions, using equations (7) and (8):

    1. Rated load, unity power factor
    2. Rated load, 0.8 lagging power factor
    3. Rated load, 0.8 leading power factor.

7. Synchronization Circuits

7.1 Circuit Diagram

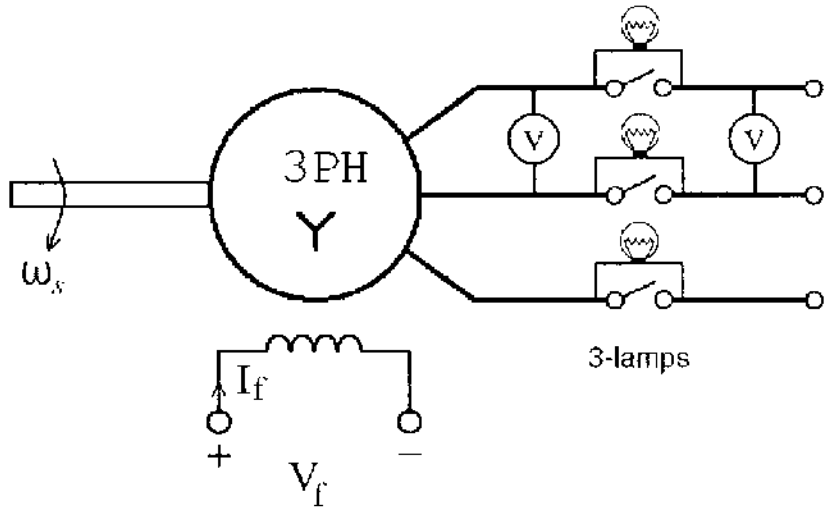


Figure 5 : Synchronization Circuit

7.2 Circuit Assembly

Assemble the measurement circuits according to the above circuit diagram.

7.3 Experiment Procedure

The process of properly connecting a synchronous generator in parallel with the other generators in the power system, or to the infinite bus, is called synchronization. In order to synchronize properly, the following conditions have to be satisfied:

1. The magnitude of the terminal voltage of the incoming generator must be the same as the voltage at the point of interconnection with the power system of infinite bus.
2. The frequency of the incoming generator must be the same as the frequency of the power system or infinite bus.
3. The generator must have the same phase sequence as the infinite bus.
4. The phase angles of corresponding phases of the incoming generator and the power system must be equal.

To verify that these conditions for connecting the incoming generator in parallel with the infinite bus are satisfied, a set of three synchronization lamps may be used. The circuit diagram for the connection of these lamps for synchronization is shown above.

The field current varies until the generator becomes equal to, or slightly greater than, the infinite bus voltage. If the phase sequences of the generator and the infinite bus are different, the three lamps will brighten up alternately. To correct for this improper condition, any two of the three connections to the synchronous generator are interchanged. If the phase sequence is correct, the lamps are all bright or are all dark at the same time. If the frequencies are slightly different, the three lamps will brighten or darken at the same time. The speed of the prime mover of the synchronous generator is adjusted so that the generator's frequency is the same as that of the infinite bus, at which time all lamps stay dark. When all four conditions are satisfied simultaneously, the circuit breaker is closed, and the generator is now operating in parallel with the rest of the synchronous machines of the systems.

Experiment # 7: Multi-Function Machine as Three-phase Synchronous Motor

1. Objectives:

- Connection, Starting, Reversing of Rotation Direction, Checking Rating Plate Data of a Multi-function Machine as Synchronous Motor
- (a) Load characteristics **n, I, cos φ, η, S, P_1, P_2 = f (M) at cos φ_N = 1**
  (b) Load characteristics **I_E, n, I, cos φ, η, S, P_1, P_2 = f (M) at cos φ_N = 1 =** Constant
- 3. Multi-function Machine as Synchronous Motor in Phase Shifting Operation V-Characteristics **I = f (I_E)**

2. Equipments:

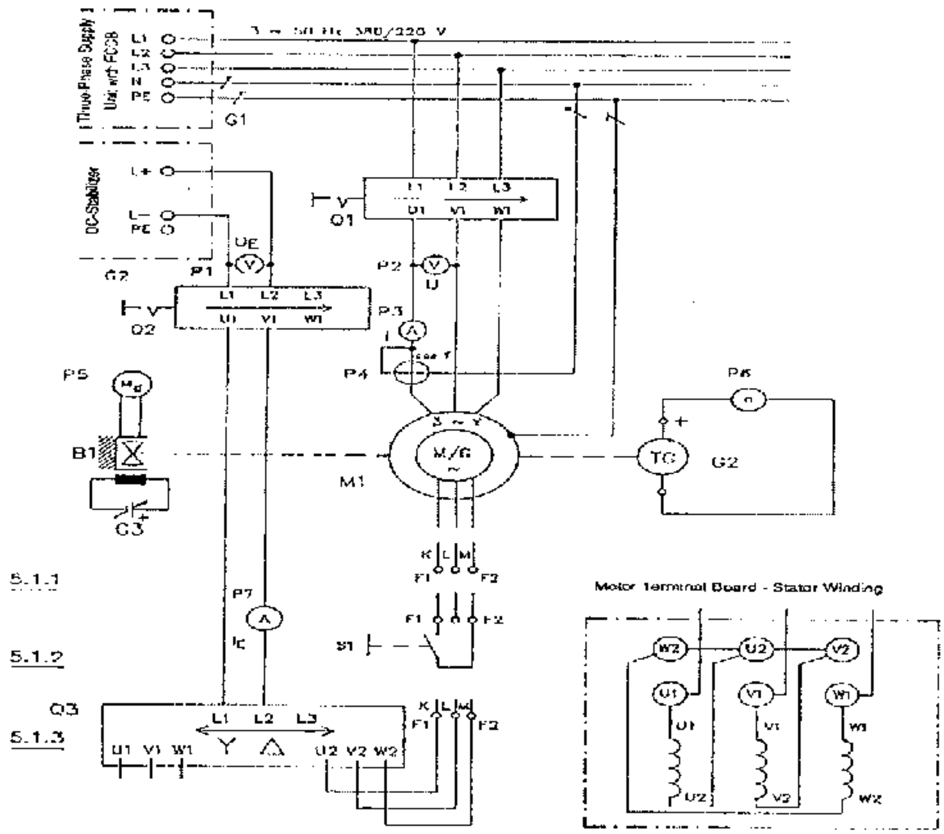
- Three-phase Supply
- On/Off Switches Three-phase
- Star/Delta Switch
- Pushbutton, single
- Magnetic Powder Brake
- Control Unit
- Tacho Generator
- Multi-function Machine
- Rotor Starter
- Power Factor Meter
- RMS Meters
- Power Meter

3. Multi-function Machine as Synchronous Motor

- **Connection, Starting, Reversal of Rotation Direction, Checking Rating Plate Data of a Multi-function Machine as Synchronous Motor**

3.1 Connection and Starting of a Multi-function Machine as Synchronous Motor

3.1.1 Circuit Diagram



3.1.2 Circuit Assembly

Assemble the measurement circuits according to the circuit diagram and connect the motor terminal board.

3.1.3 Experiment Procedure

After the teacher has checked ad approved the circuit, put the circuit into operation and observe the starting behavior of the motor at no-load, i.e. residual friction of the brake. After run-up has been achieved load the motor with the values as specified in the table. Carry out the observations as follows (see circuit diagram 3.1.1):

3.1.3.1 Opened exciter winding

3.1.3.2 Short-circuited exciter winding

3.1.3.3 Exciter voltage applied to exciter winding

The switch Q_3 in the Y-position here first connects the terminals K-L-M of the rotor, the multi-function machine runs up asynchronously. At approximately synchronous speed the configuration is switched over to the Δ-position. These results in the DC excitation being connected to the rotor, the motor is pulled into synchronization.

Setting of the Magnetic Powder Brake on the Control Unit

Before operation set the control unit as follows:

Control Unit	1.0
Speed Range Switch "min^{-1}"	3000
Torque Range Switch "Nm"	10
Operation Mode Switch	MAN 1

Put the motor into operation and enter the required values in the tables below!

3.1.3.4 Calculation of the Nominal Torque

Take the data from the rating plate of your machine in order to calculate the nominal torque as well as for the evaluation of the measurement results. As example;

$P_N = 800$ W **$U_N = 220/380$ V** **$I_N = 2.42 / 1.4$**

$n_N = 1500\ min^{-1}$ **$\cos\varphi = 1$**

$U_E = 7.8$ V **$I_E = 8.8$ A**

$M_N = P_N \cdot 9.55 / n_N$

$= 5.1$ Nm

3.1.3.5 Results Table

3.1.3.5.1

Multi-function Machine as Synchronous Motor 1.0 - Open Exciter Winding -						
U/V	380					
M/Nm	0.2 Residual Friction					
n/min^{-1}	0	Motor stops				
I/A	0.95					
cos φ	0.1					

3.1.3.5.2

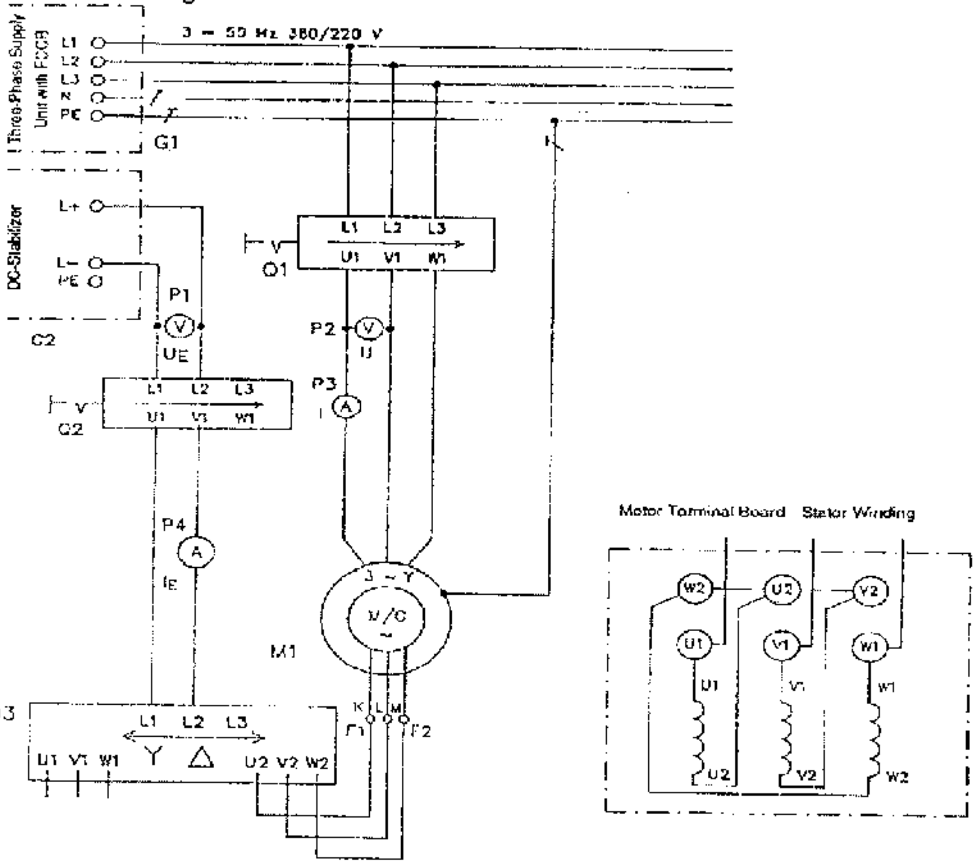
Multi-function Machine as Synchronous Motor 1.0 - Closed Exciter Winding -						
U/V	380					
M/Nm	0.6 Residual Friction	1.0	2.0	3.0	4.0	5.0	5.1 (M_N)
n/min^{-1}							
I/A							
cos φ							

3.1.3.5.3 For this, switch the star-delta switch Q_3 for run up to position Y, then to Δ position (see 3.1.1) set the cos φ_0 to the value cos $\varphi_0 = 1$ using the exciter current.

Multi-function Machine as Synchronous Motor 1.0 - Exciter voltage applied to Exciter Winding -								
U/V	380							
M/Nm	0.5 Residual Friction	1.0	1.5	2.0	2.5	3.0	3.5	4.0
n/min⁻¹								falls out of synchronization
I/A								
cos φ								
U_E/V								
I_E/V								

3.2 Rotation Reversal of a Multi-function machine as Synchronous Motor

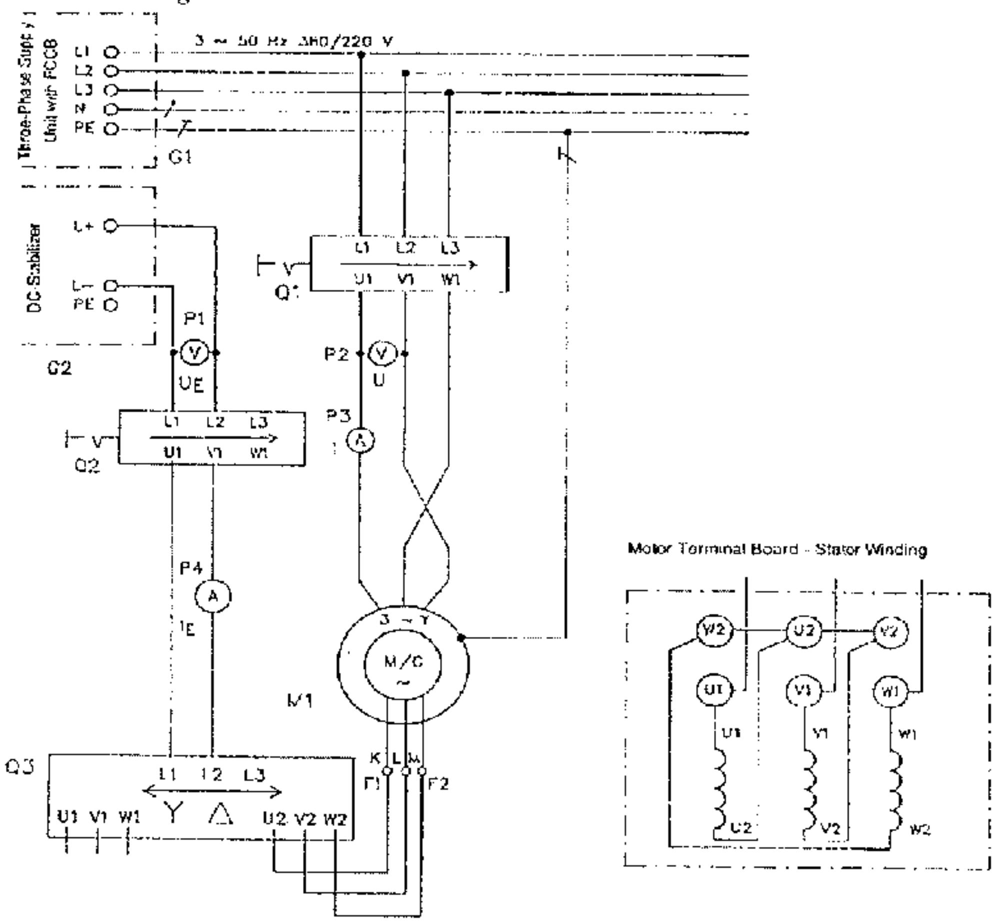
3.2.1 Circuit Diagram - Clockwise



3.2.1.1 Circuit Assembly

Assemble the measurement circuit as specified in the diagram above and check the rotation direction. Apply an exciter voltage of 9.5 V (?) for this!.

3.2.2 Circuit Diagram- Counter Clockwise



3.2.2.1 Circuit Assembly

Complete the measurement circuit for counter clockwise rotation! Assemble the measurement circuit and check the rotation direction.
Set the exciter voltage to 9.5 V (?) for this!

3.3 Checking the Rating Plate of a Multi-function Machine as Synchronous Motor

3.3.1 Rating Plate Data

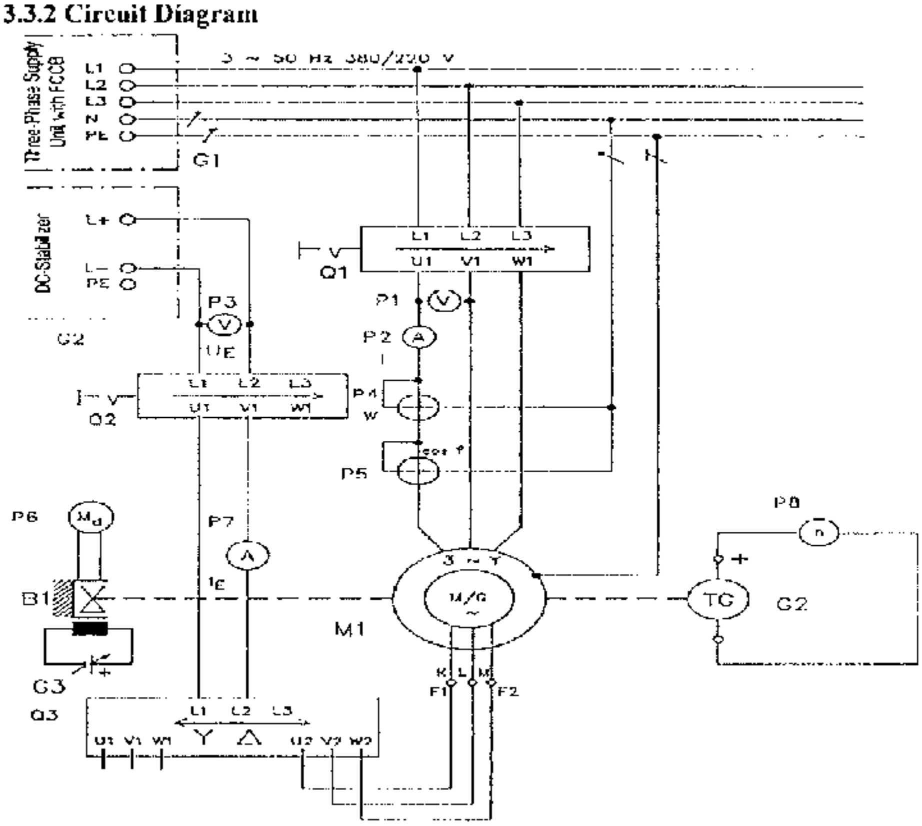
Enter the data give on the rating plate of the multi-function as synchronous motor into the rating plate given below (as, an example)

LEYBOLD—DIDACTIC GMBH		
Typ 732 98		
3~ Motor	Nr. 200 65 009	
Δ/Y 220/380 V	2,42/1,4 A	
0,8 kW	S 1	cos φ 1
1500 min^{-1}	50 Hz	
ERR. 7,8 V	8,8 A	
I.KL. B	IP 44	
VDE 0530		

Calculate the nominal torque of the motor (As an example)

$$M_N = P_N \cdot 9.55 / n_N$$
$$= 800 \cdot 9.55 / 1500\ \text{min}^{-1}$$
$$= 5.1\ \text{Nm}$$

3.3.2 Circuit Diagram



3.3.3 Circuit Assembly
Assemble the measurement circuit according to the circuit diagram to determine the rating plate data!

3.3.4 Experiment Procedure
After the teacher has checked and approved the circuit put the circuit into operation and carry out the following exercises. For this first set the star-delta switch Q3 to position Y for the run up and then to Δ position. Load the motor with the nominal torque M_N, whereby the exciter voltage U_E is to be adjusted in such a way that the power factor is, the speed n, the exciter voltage $\cos \varphi = 1$. Then determine the current consumed I, the power supplied P_1, the speed n, the exciter voltage U_E, the exciter current I_E and using these results, calculate the power delivered P_2 and the efficiency.

Setting the Magnetic Powder Brake on the Control Unit
Before operation set the control unit as follows:

Control Unit	1.0
Speed Range Switch "min-1"	3000
Torque Range Switch "Nm"	10
Operation Mode Switch	MAN 1

Put the motor into operation.

3.3.5 Results
Enter the measured and calculated values into the results table

3.3.5.1 Results Table

Multi-function Machine as Synchronous Motor 1.0											
U / V	M / Nm	n / min^{-1}	I / A	P_{1phase} / W	P_1 / W	cos φ	U_E / V	I_E / A	P_2 / W	η	
											Measurement
											Calculation

3.3.6 Calculation
Calculate the delivered power of the multi-function machine as synchronous motor at nominal load.

$$P_2 = M_N \cdot n_N / 9.55$$

4. Load Characteristics of a Multi-function Machine as Synchronous Motor

- **Load Characteristics n, I, cos φ, η, P_1, P_2 = f (M) at $\cos \varphi_N = 1$**

- **Load Characteristics I_E, n, I, η, P_1, P_2 = f (M) at cos φ = 1 constant**

4.1 Theory

The Synchronous motor has a constant operation speed after it has run-up asynchronously with the aid of a squirrel cage winding in the rotor and has been pulled into synchronization. This is equal to the synchronous speed of the rotating field of the stator and does not alter with normal load fluctuations.

Synchronous motors operate with a slip of s=0%.

The input power P1 is measured in an outer conductor using a power meter. Since the load is symmetrical, the measured power value can be multiplied by 3 to get the total consumed power.

$$P1 = 3 \cdot P_{phase}$$

If the torque M and the speed n have been determined for various loads, the corresponding motor power P2 delivered can be determined.

$$P2 = M \cdot \omega$$

Since

$$\omega = 2 \pi n / 60$$

Therefore,

$$P2 = M \cdot n / 9.55$$

The efficiency is given by the ratio:

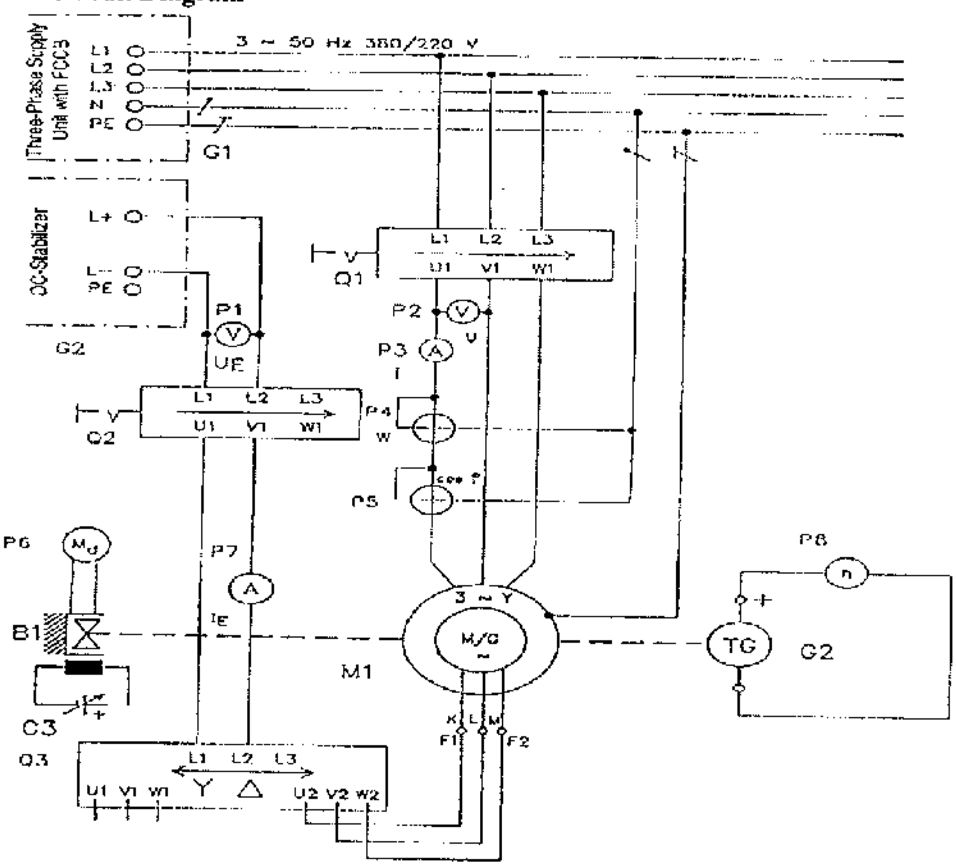
$$\eta = P_2 / (P_1 + P_E) \;;\; P_E = U_E \cdot I_E$$

The power factor is determined in an outer conductor with a power factor meter from the equation:

$$\cos \varphi = P1 / (\sqrt{3} \cdot U \cdot I)$$

4.2 Determination of the Load Characteristics n, I, cos φ, η, P_1, P_2 = f (M) at cos φ_N = 1 of a Multi-function Machine as Synchronous Motor

4.2.1 Circuit Diagram



4.2.2 Circuit Assembly

Assemble the measurement circuits according to the circuit diagram to determine the required values.

4.2.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation and carry out the following exercises. For this set the star-delta switch Q_3 first to Y position for run up then to Δ position.

Load the motor between no-load (residual friction of the brake) operation and approx. 1.25 times the nominal value. First, by changing the exciter voltage at the voltage source G2, set the exciter current to the values given in the able so that when the motor is loaded with its nominal values a power factor cos φ = 1 is set.

Then proceed with the experiment using the given load values and measure the speed n, the current consumption I, the power factor cos φ and the power consumed P_1.

Setting the Magnetic Powder Brake on the Control Unit

Before operation set the control unit as follows:

Control Unit	1.0
Speed Range Switch "min^{-1}"	3000
Torque Range Switch "Nm"	10
Operation Mode	MAN 1

Put the motor into operation. First run up the motor, at no-load, to its nominal speed range and then, after run-up has been achieved, begin with the setting at G_2.

4.2.4 Results

Enter the determined measured and calculated values into the following results table.

4.2.4.1Results Table

Multi-function Machine as Synchronous Motor 1.0								
Setting at G2 at $M_N = 5.1$ Nm	I_E/mA	6.9						
	U_E/V	9.5						
Measurement	M/Nm	0.6	1.0	1.5	2.0	2.5	3.0	3.5
	n/min^{-1}							
	I/A							
	cos φ							
	P_{phase}/W							
Calculation	$P_1 + P_E$/W							
	P_2/W							
	η							

Multi-function Machine as Synchronous Motor 1.0								
Setting at G2 at $M_N = 5.1$ Nm	I_E/mA	6.9						
	U_E/V	9.5						
Measurement	M/Nm	4.0	4.5	5.0	5.1 (M_N)	5.5	6.0	
	n/min^{-1}							
	I/A							
	cos φ							
	P_{phase}/W							
Calculation	$P_1 + P_E$/W							
	P_2/W							
	η							

4.2.5 Calculation

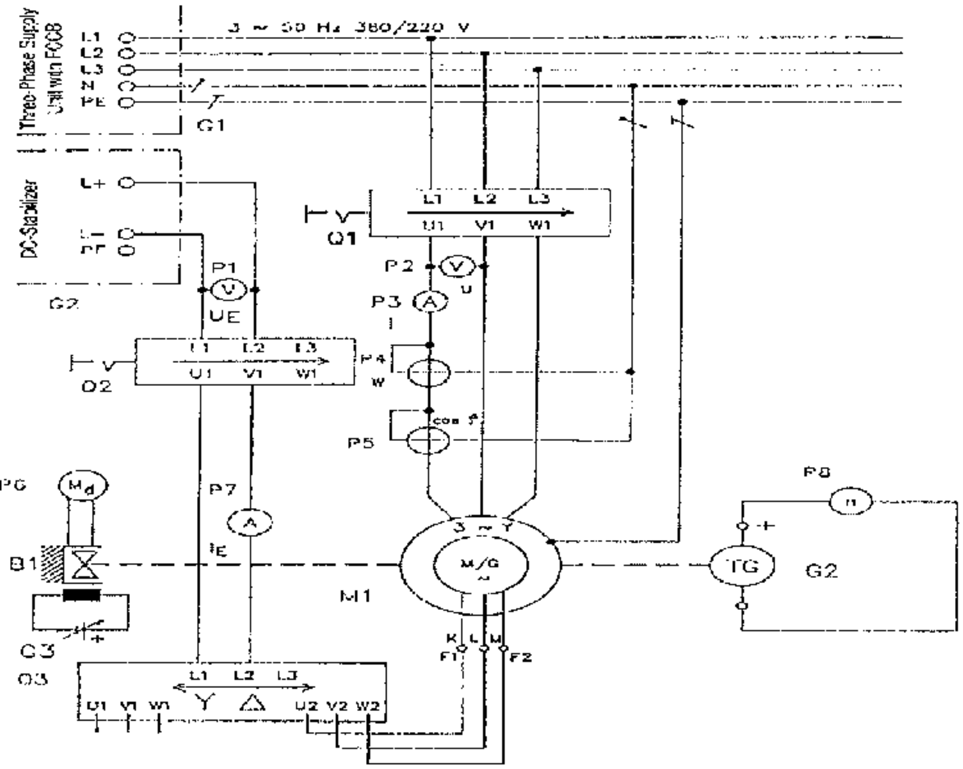
Calculate the values required for completion of the results table and enter them into the table. Show the calculation steps for measurement at load with nominal torque.

4.2.6 Load Characteristics

Using the measured and calculated values, draw on a graph the curves for the multi-function machine as synchronous motor. Draw a vertical line for the nominal torque on the graph.

4.3 Determination of the Load Characteristics IE, n, I, η, P_1, P_2 = f (M) in a Multi-Function Machine as Synchronous Motor with cos φ = 1 constant

4.3.1 Circuit Diagram



4.3.2 Circuit Assembly

Assemble the measurement circuits according to the circuit diagram to determine the required values.

4.3.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation and carry out the following exercises.

For this set the star-delta switch Q_3 first to Y position for run up then to Δ position.

Load the motor between no-load (residual friction of the brake) operation and approx. 1.25 times the nominal value. Change the exciter voltage each time at the voltage source G_2 so that when the motor is loaded with the given load values a power factor cos φ = 1 is always set.

Then proceed with the experiment using the given load values and measure the exciter current I_E, speed n, the current consumption I, and the power consumed P_1

Setting the Magnetic Powder Brake on the Control Unit

Before operation set the control unit as follows:

Control Unit	1.0
Speed Range Switch "min⁻¹"	3000
Torque Range Switch "Nm"	10
Operation Mode	MAN 1

Put the motor into operation. First run-up the motor, at no-load, to its nominal speed and then after run-up has been achieved begin with the settings at G_2.

4.3.3 Results

Enter the determined measured and calculated values into the following results table.

4.3.3.1 Results Table

Multi-function Machine as Synchronous Motor 1.0								
Measurement	cos φ	1						
	M/Nm	0.4	1.0	1.5	2.0	2.5	3.0	3.5
	n/min^{-1}							
	U_E/V							
	I_E/A							
	I/A							
	P_{phase}/W							
Calculation	P_1/W							
	P_E/W							
	P_2/W							
	η							

Multi-function Machine as Synchronous Motor 1.0								
Measurement	cos φ	1						
	M/Nm	0.4	1.0	1.5	2.0	2.5	3.0	3.5
	n/min^{-1}							
	U_E/V							
	I_E/A							
	I/A							
	P_{phase}/W							
Calculation	P_1/W							
	P_E/W							
	P_2/W							
	η							

4.3.4 Calculation

Calculation the values required for completion of the results table. Show the calculation steps for measurement at load with nominal torque.

4.3.5 Load Characteristics

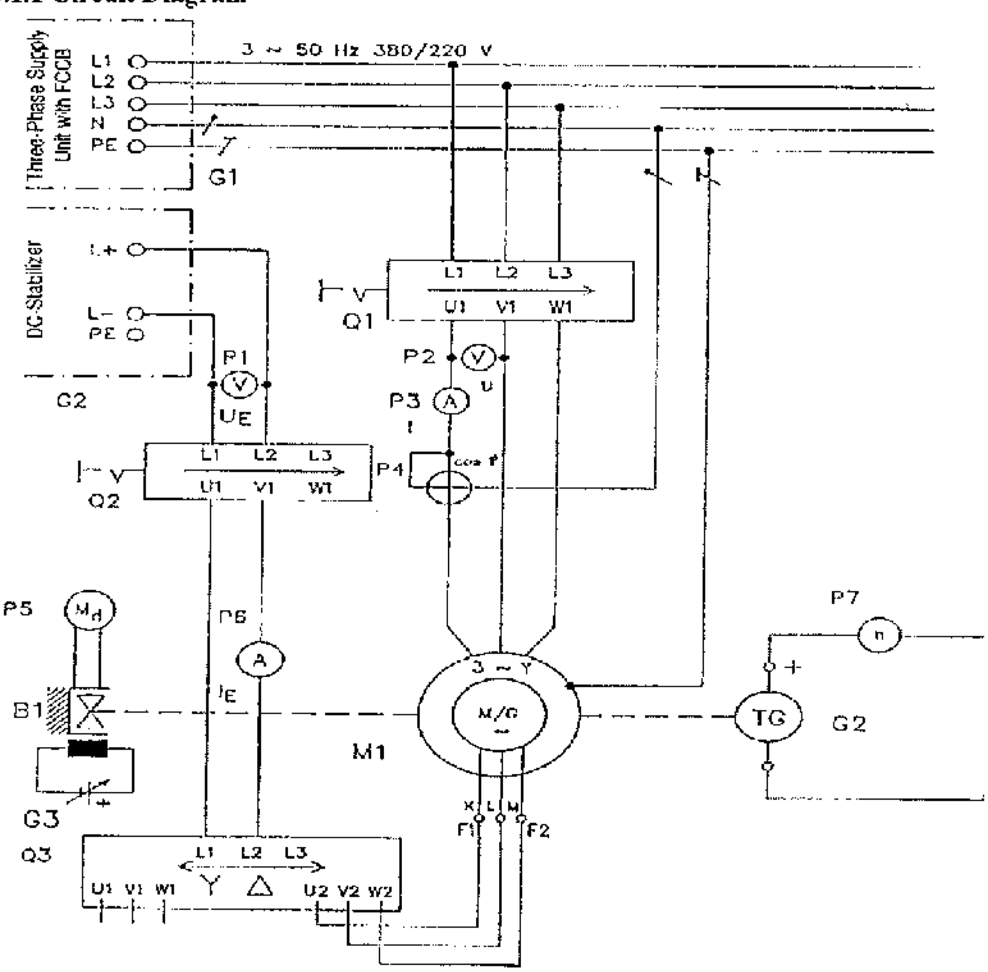
Using the measurement and calculated values, draw, on a graph, the curves for the multi-function as synchronous motor.
Draw a vertical line for the nominal torque on the diagram.

5. Multi-function Machine as Synchronous Motor in Phase shifting Operation

- **V-Characteristics $I = f(I_E)$**

5.1 Recording the V- Characteristics $I = f(I_E)$ of a Multi-function Machine as Synchronous Motor

5.1.1 Circuit Diagram



5.1.2 Circuit Assembly
Assemble the circuits according to the circuit diagram to determine the required values.

5.1.3 Experiment Procedure
After the teacher has checked and approved the circuit, put the circuit into operation and carry out the following exercises.
For this set the star-delta switch Q_3 first to Y position for run up then to Δ position.
Keep the load M of the motor constant for each measurement sequence. The exciter current I_E to be set as specified in the table is carried out by changing the exciter voltage at the voltage source G_2.
Measure the supply current I received as well as the exciter current IE when the power factor cos φ = 1 has been reached. Reduce the exciter current IE step by step and measure the value when the stability limit is reached, i.e. as soon as the motor falls out of synchronization.

<u>Setting the Magnetic Powder Brake on the Control Unit</u>
Before operation set the control unit as follows:

Control Unit	1.0
Speed Range Switch "min^{-1}"	3000
Torque Range Switch "Nm"	10
Operation Mode	MAN 1

Put the motor into operation. First run-up the motor, at no-load, to its nominal speed and then after run-up has been achieved begin with the settings at G_2.

5.1.4 Results
Enter the determined measured and calculated values into the following results table.

<u>5.1.4.1</u> Results Multi-function Machine as Synchronous Motor 1.0

M = 1.0 Nm constant	underexcited					cos φ = 1	overexcited						Stability limit Motor falls out of synchronization
I_E/A													
I/mA													$I_E \leq 1.3$ A

5.1.4.2

M = 3.0 Nm constant	underexcited				$\cos\varphi = 1$	overexcited					
I_E/A											
I/mA											

Stability limit Motor falls out of synchronization
$I_E \leq 3.5$ A

5.1.4.3

M = 5.0 Nm constant	underexcited			$\cos\varphi = 1$	overexcited					
I_E/A										
I/mA										

Stability limit Motor falls out of synchronization
$I_E \leq 5.8$ A

5.1.5 V-Characteristics

Using the measured values, draw, on a graph, the curves for the multi-function machine as synchronous motor.

Experiment # 8: Multi-Function Machine as Three-phase Induction Motor with Slip Ring Rotor

1. Objectives:

- Load characteristics **n, I,** cos φ, η, S, P1, P2 = **f** (M)
- Run-up characteristics **M = f (n)**, I = f **(n)** for various Rotor Resistors
- Speed Setting with Rotor Starter Resistors **n = f (Rv)**

2. Equipments:

- Three-phase Supply
- Reversing switch
- Magnetic Powder Brake
- Control Unit
- Tacho Generator
- Multi-function Machine
- Rotor Starter
- Power Factor Meter
- RMS Meter

3. Multi-function Machine as Three-phase Induction Motor with Slip Ring Rotor Load Characteristics n, I, cos φ,η, S, P1, P2 = f (M)

3.1 Theory:

The load is set using a magnetic powder brake with control unit. The AC voltage of the three-phase mains supply is to be kept constant at 380 V during measurements.
The input power **P1** is measured in an outer conductor using a power meter. Since the load is symmetrical, the measured power value can be multiplied by **3** to get the total consumed power.

$$P_1 = 3 \cdot P_{phase}$$

If the torque M and the speed n have been determined for various loads, the corresponding motor power P2 delivered can be determined.

$$P_2 = M \cdot \omega$$

Or

$$P_2 = M \cdot n / 9.55$$

The efficiency is given by the ratio;

$$\eta = P_2 / P_1$$

The power factor is determined from:

$$\cos \varphi = P_1 / (\sqrt{3} \cdot U \cdot I)$$

The slip of the motor can be calculated at various loads from the equation:

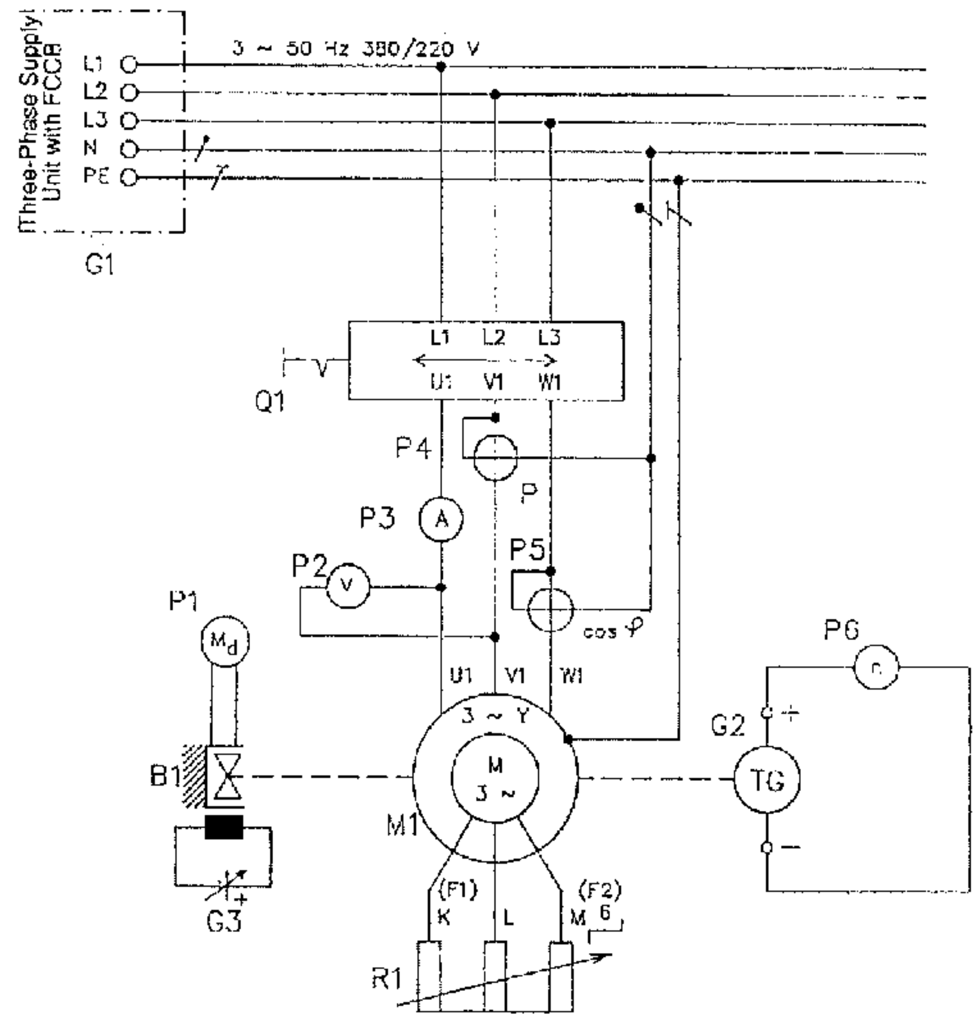
$$S = (n_s - n) / n_s$$

n_s = synchronous speed in min^{-1}

n = rotor speed in min^{-1}

S = slip

3.2 Circuit Diagram



3.3 Circuit Assembly

Assemble the measurement circuit according to the circuit diagram to determine the required values.

3.4 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. After run-up, switch the rotor starter to **0 Ω** and load the motor between no-load operation and approximately 1.5 times the nominal torque.

Measure the speed **n**, the effective consumed power P_{1phase}, the supply current I_1, and the power factor **cos φ** of the motor.

Setting the Magnetic Powder Brake on the Control Unit

Before operation set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min^{-1}"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

3.5 Results

Enter the determined measured and calculated values into the following results table.

3.5.1 Results

Multi-function Machine as Slip Ring Motor 1.0												
Measurement	M/Nm	0.5	1	2	3	4	5	6	7	8	9	10
	r/min^{-1}											
	I_1/A											
	cos φ											
	P_{1phase}/W											
Calculation	P_1/W											
	P_2/W											
	η											
	s/%											

3.6 Calculation

Calculate the values required for completion of the results table and enter them into the table. Show the calculation steps for measurement at load with nominal torque.

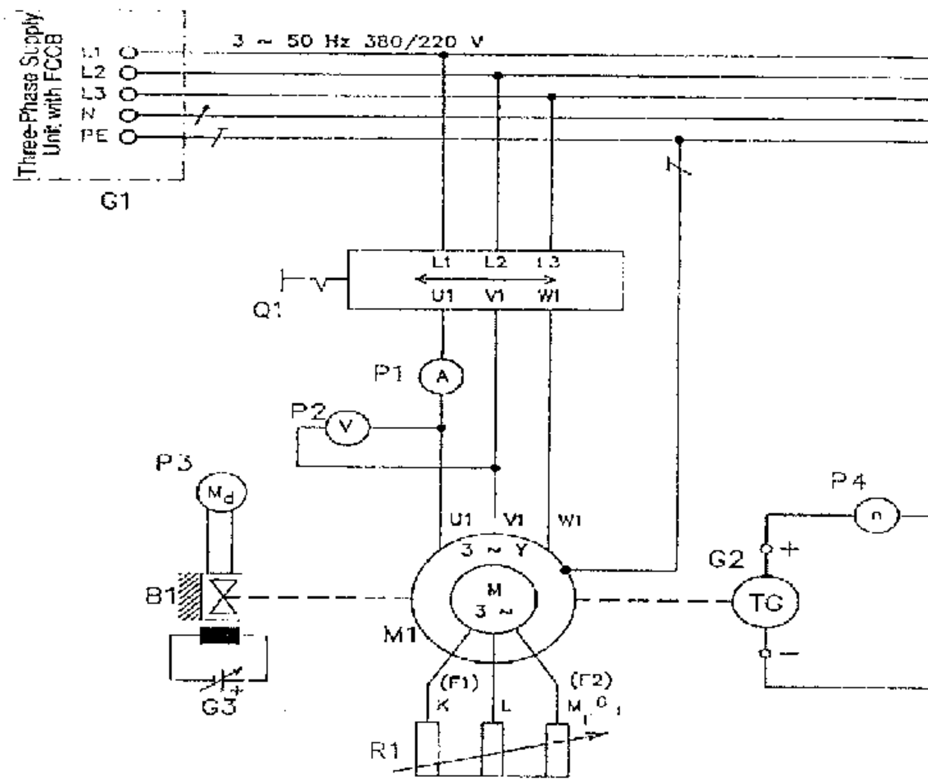
3.7 Load Characteristics

Using the measured and calculated values, draw, on a graph the curves for the motor when the rotor is in the short-circuit mode of operation.
Draw a perpendicular line for the nominal torque on the diagram.

4. Multi-function Machine as Three-phase Induction Motor with Slip Ring Rotor Run-up Characteristics M = f (n), I = f (n) for Various Rotor Resistors

4.1 Measurement of the Run-up Characteristics of a Multi-function Machine as Three-phase Slip Ring Motor with Various Rotor Starter Resistor

4.1.1 Circuit Diagram



4.1.2 Circuit Assembly

Assemble the measurement circuit according to the diagram for determining the run-up characteristics!

4.1.3 Experiment procedure

After the instructor has checked and approved the circuit, put the circuit into operation. Make sure that the brake is completely open.

After it has run up, break the motor from no-load operation to standstill. Commence the measuring with the largest rotor starter resistor R_V = 10 Ω.Measure the speed and the values of the torque and stator current.

<u>**Setting the Magnetic Powder Brake on Control Unit**</u>

Before operation, set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min^{-1}"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

Put the motor into operation
Complete the measuring as quickly as possible, because the rated motor current is exceeded under load and motor is therefore at times overloaded, which leads to disengagement of the brake operation via a thermal switch.

4.1.4 Results

Enter the measured values into the results table!

4.1.4.1 Results Table

	$n/\,min^{-1}$									
R_V = 10 Ω Rotor starter position 1	M/Nm									
	I_1/A									
R_V = 5 Ω Rotor starter position 2	M/Nm									
	I_1/A									
R_V = 2.75 Ω Rotor starter position 3	M/Nm									
	I_1/A									
R_V = 1.25 Ω Rotor starter position 4	M/Nm									
	I_1/A									
R_V = 0.5 Ω Rotor starter position 5	M/Nm									
	I_1/A									
R_V = 0 Ω Rotor starter position 6	M/Nm									
	I_1/A									

4.1.5 Diagram

Plot the Run-up characteristics **M = f (n); I = f (n)** of the multi-function machine as three-phase slip ring at various values of rotor resistance.

5. Multi-function Machine as Three-phase Induction Motor with Slip Ring Rotor Speed Setting with Rotor Starter Resistors n = f (Rv)

5.1 Theory:

There are various methods of setting the speed in a three-phase induction motor:

$$n = f_1 \cdot (1-s) / p$$

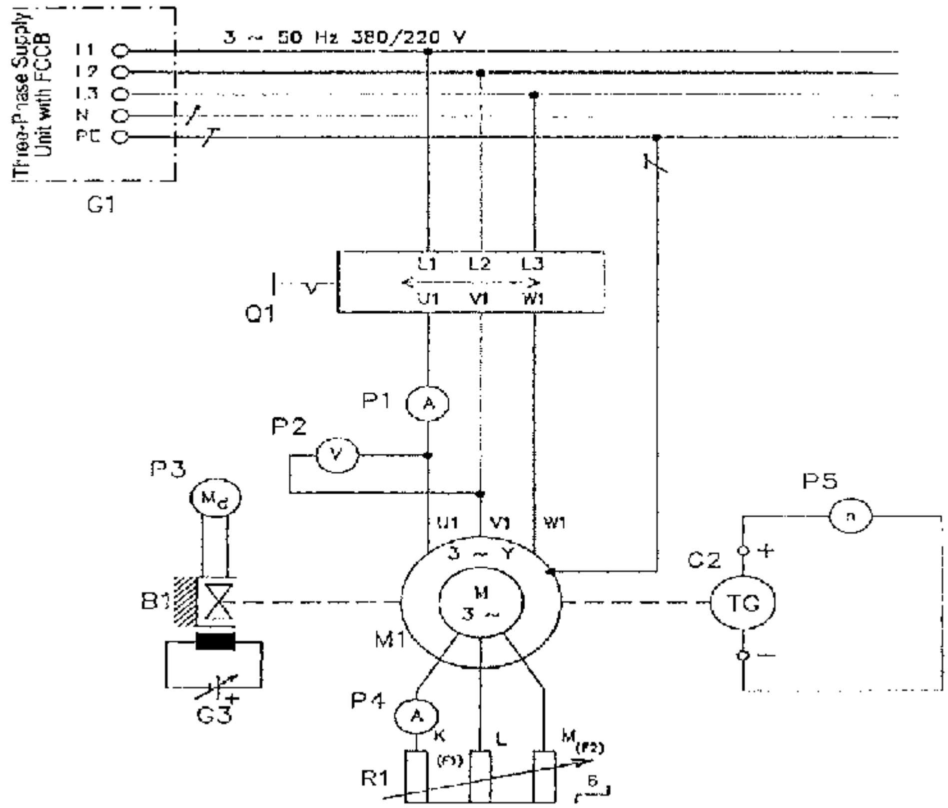
Where
n = rotor speed
f_1 = mains voltage frequency
p = number of pole pairs in the stator windings
s = slip
The following expression is valid for loading at nominal torque foe example:

$$S_N/S_2 = R_{rotor}/(R_{rotor} + R_v)$$

Where
S_N = slip at nominal torque load without rotor starter resistance
S_2 = slip at nominal torque load with rotor starter resistance **Rv**
R_{rotor} = resistance of rotor winding
R_v = rotor starter resistance

5.2 Speed Control of a Multi-function Machine as Three-phase Slip Ring Induction Machine

5.2.1 Circuit Diagram



5.2.2 Circuit assembly

Assemble the measuring circuit according to the circuit diagram to determine the influence of the rotor starter resistors on the speed.

5.2.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Measure the speed of the multi-function machine as three-phase induction motor with slip ring at nominal load with various rotor resistance values.

<u>Setting the magnetic Powder Brake on the Control Unit</u>

Before operation set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min^{-1}"	3000
Torque range Switch "Nm"	**10**
Operation Mode Switch	MAN1

Put the motor into operation
After run-up, switch the rotor starter to 0 Ω and load the motor to its nominal torque: M_N = 3.4 Nm.
Measure the speed, the stator current and the rotor current of the motor. The rotor starter resistors are then connected step by step and these measurements repeated for each resistor according to the results table below!

5.2.4 Results
Enter the measured values into the following results table.

5.2.4.1 Results Table

Multi-function Machine as Slip Ring Motor 1.0						
Setting of Rotor Starter	6	5	4	3	2	1
R_V/Ω	0	0.5	1.25	2.75	5	10
n/min^{-1}						
I_1/A						
I_2/A						

5.2.5 Diagram
Plot the measured values of speed n and rotor resistance Rv on a graph.

5.3Measurement
Behavior of three-phase induction with slip ring speed in relation to various rotor resistance values

5.3.1 Circuit Assembly
Assemble the measurement circuit 5.2.1 according to the circuit diagram; without ammeter P_1

5.3.2 Experiment Procedure
Before operation set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min⁻¹"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

Put the motor into operation.
For each rotor starter resistor load the motor between no-load operations and approx. 1.5 times the nominal torque. For each starter resistor measure the motor speed.

5.3.3 Results

Enter the measured values in the following results table.

5.3.3.1 Results Table

Multi-function Machine as Slip Ring Motor 1.0									
Setting of Rotor Starter	R_V/Ω	M_L/Nm	0.5	2.0	4.0	6.0	7.0	8.0	10.0
6	0	n/min⁻¹							
5	0.5	n/min⁻¹							
4	1.25	n/min⁻¹							
3	2.75	n/min⁻¹							
2	5	n/min⁻¹							
1	10	n/min⁻¹							

5.3.4 Diagram

Draw the load characteristics of the multi-function machine as three-phase induction motor with slip ring on a graph. Designate the individual characteristics with the appropriate resistance value of the rotor starter.

Experiment # 9: Three-Phase Squirrel Cage Induction Motor

1. Objectives:

- Connection, Rotation Reversing, Star Connection, Delta Connection
- Load characteristics **n, I, cos** φ, η, **S, P1, P2 = f (M)**
- Run-up characteristics **M = f (n), I = f (n)** for Star and Delta Connection

2. Equipments:

- Three-phase Supply Unit
- Reversing switch
- Magnetic Powder Brake
- Control Unit
- Tacho Generator
- Squirrel Cage Induction Motor
- Rotor Starter
- Power Factor Meter
- RMS Meters

3. Connections, Rotation Reversing, Star Connection, Delta Connection

3.1 Information

3.1.1 General

The three-phase squirrel cage induction motor consists of a stationary part, the stator and a rotating part, the rotor or armature. Both are constructed from dynamo sheet. The stator carries a three-phase winding. The stator winding ends are connected to 6 terminals on the terminal board-Fig.1

There are large rods, usually aluminum, in the rotor grooves, the rods are connected via two short-circuit rings. Without the bundle of laminations the rotor winding represents a cage.

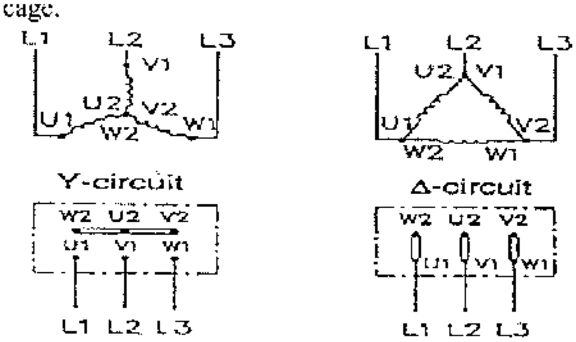


Fig. 1: Stator Winding and Terminal Board of a Squirrel Cage Motor for Clockwise Rotation

3.1.2 Connection

Connecting the stator winding to the three-phase supply creates a rotating field in the stator. The stator winding is to be switched to delta or star mode according to the existing mains voltage and the data on the rating plate.

The following rule applies for the direction of rotation: Connection of L_1 to U_1, L_2 to V_1 and L_3 to W_1 gives clockwise rotation. The direction of rotation is determined by looking at the shaft end cross section.

3.1.3 Rotation Reversal

To reverse the direction of rotation, the stator field direction has to be reversed. This is achieved by interchanging two of the mains supply lines to the stator winding- see Fig. 2.

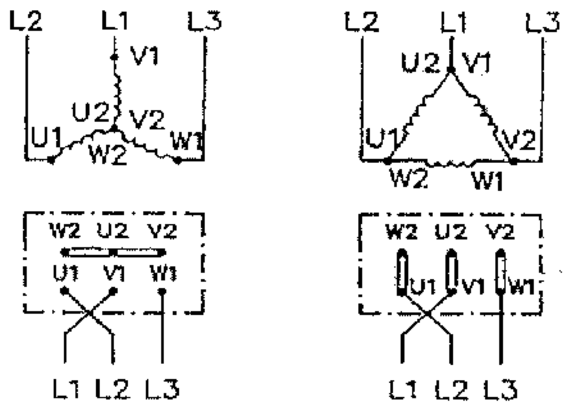
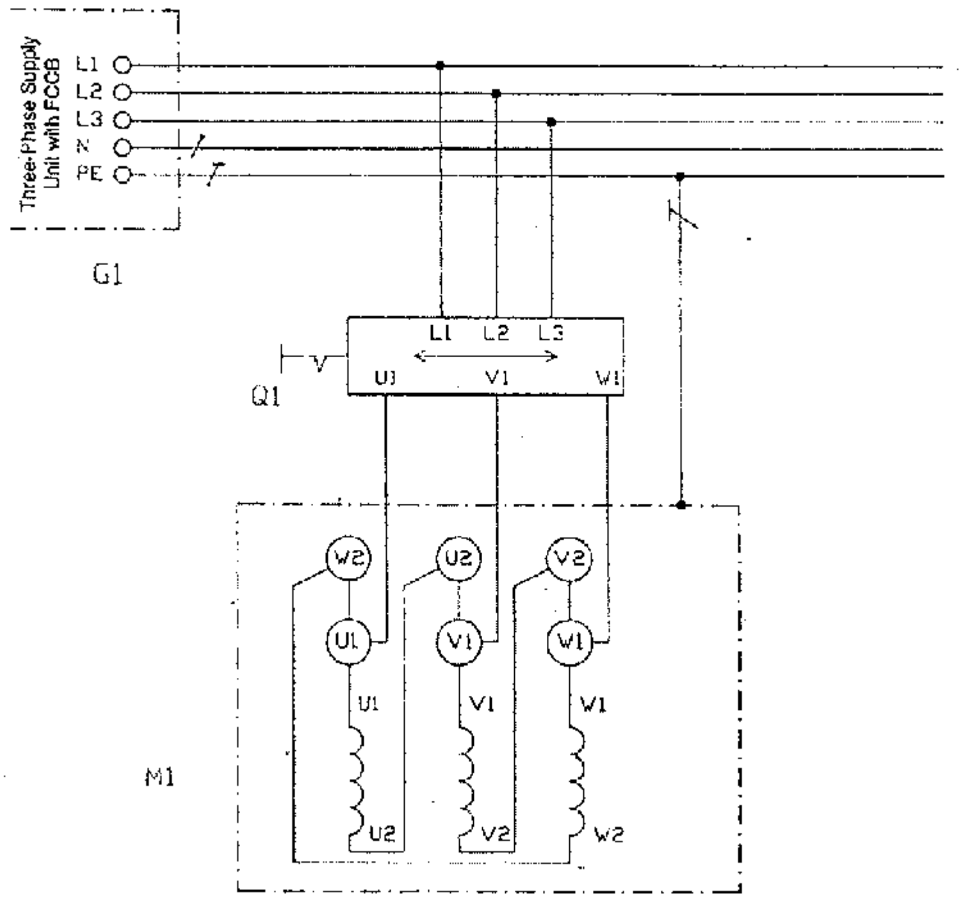


Fig. 2: Winding and Terminal Board Star and Delta Connections for Counter Clockwise Rotation

3.2 Connection and Rotation Reversal of a Three-Phase Squirrel Cage Induction Motor

3.2.1 Circuit Diagram



3.2.2 Circuit Assembly

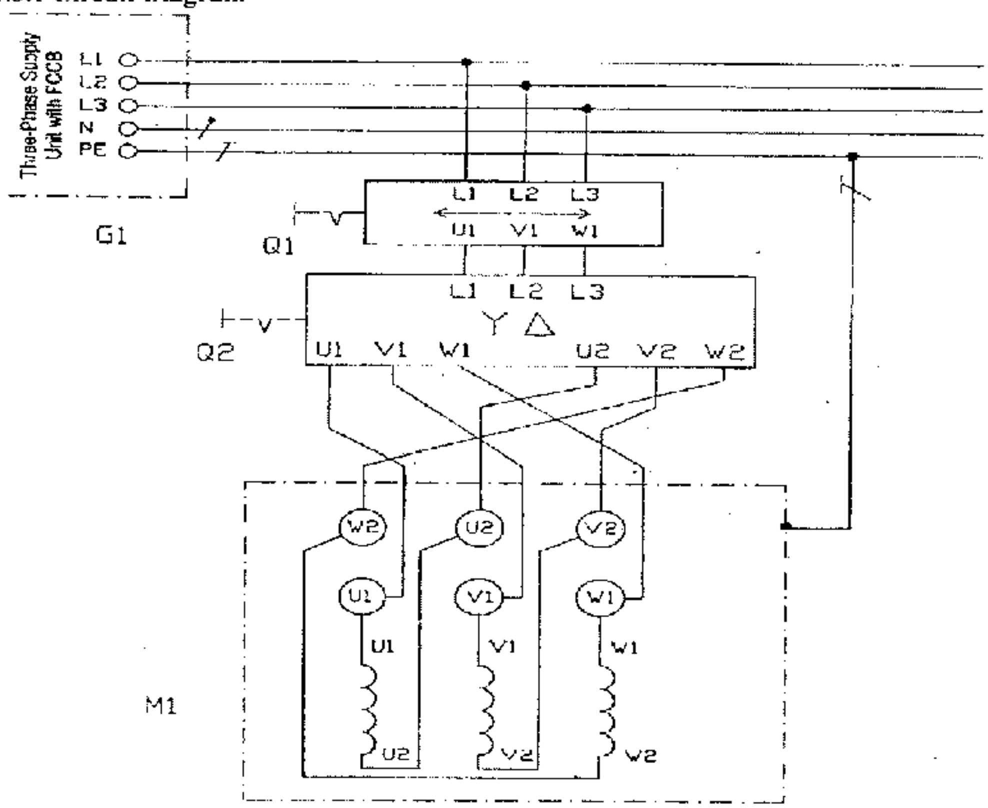
Connect the three-phase squirrel cage motor according to the circuit diagram and connect the motor terminal board. For this, take the data from the rating plate:
Nominal voltage: Y 380 V
Nominal current: 2.6 A

3.2.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Check the rotation reversal with the reversing switch Q_1.

3.3 Star-Delta Connection of a Three-phase Squirrel Cage Induction Motor

3.3.1 Circuit Diagram



3.3.2 Circuit Assembly

Connect the three-phase squirrel cage motor according to the circuit diagram and connect the motor terminal board. For this, take the data from the rating plate:
Nominal voltage: Y 380 V
Nominal current: 2.6 A

3.3.3 Experiment Procedure

After the teacher has checked and approved the circuit, put the circuit into operation. Check the rotation reversal and the star-delta start.

3.4 Determination of the Load characteristics n, I, cos φ,η, S, P1, P2 = f (M) for a Three-phase Squirrel Cage Induction Motor

3.4.1 Theory

The load is set using a magnetic powder brake with control unit. The AC voltage of the three-phase mains supply is to be kept constant at 380 V during measurements.

The input power **P1** is measured in an outer conductor using a power meter. Since the load is symmetrical, the measured power value can be multiplied by 3 to get the total consumed power.

$$P_1 = 3 \cdot P_{phase}$$

If the torque M and the speed n have been determined for various loads, the corresponding motor power P2 delivered can be determined.

$$P_2 = M \cdot \omega$$

Or

$$P_2 = M \cdot n / 9.55$$

The efficiency is given by the ratio;

$$\eta = P_2 / P_1$$

The power factor is determined from:

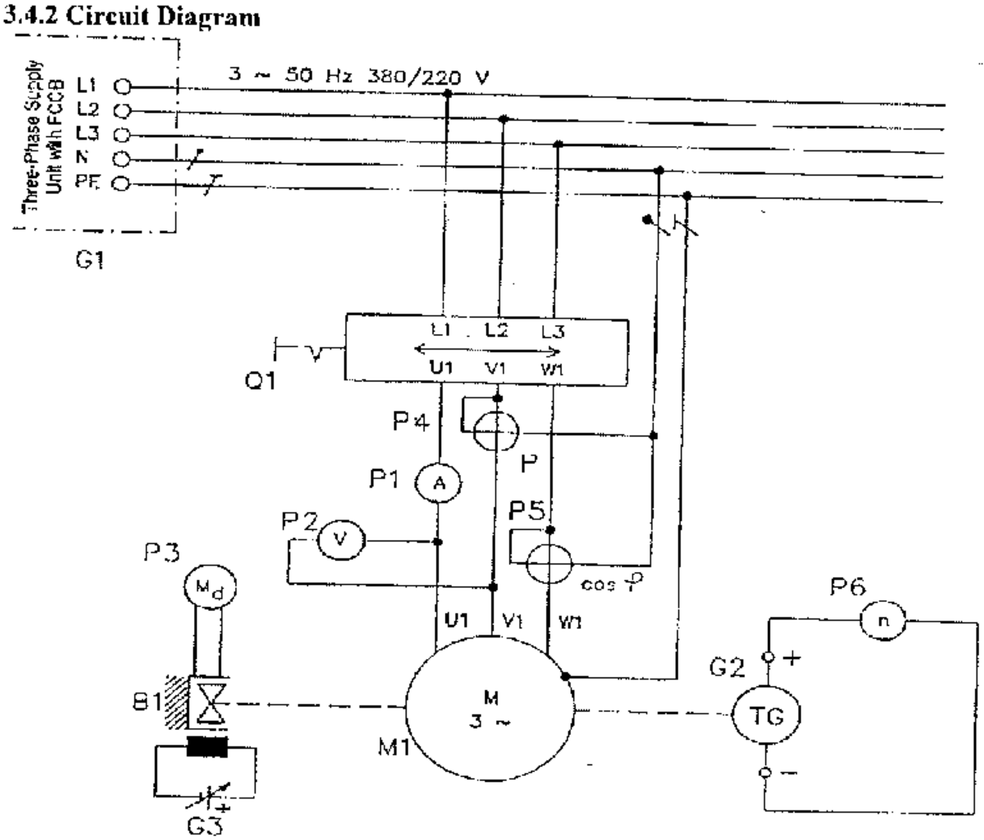
$$\cos \varphi = P_1 / (\sqrt{3} \cdot U \cdot I)$$

The slip of the motor can be calculated at various loads from the equation:

$$S = (n_s - n) / n_s$$

n_s = synchronous speed in min^{-1}
n = rotor speed in min^{-1}
S – slip in %

3.4.2 Circuit Diagram



3.4.3 Circuit Assembly

Assemble the measuring circuit according to the circuit diagram to determine the required values.

3.4.4 Experiment Procedure

After the teacher has checked ad approved the circuit, put the circuit into operation. Load the motor between no-load operations and approx. 1.5 times the nominal torque. Measure the speed n, the effective consumed power P_{1phase}, the supply current I_1 and the power factor cos φ of the motor.

Setting of the Magnetic Powder Brake on the Control Unit

Before operation set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min^{-1}"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

3.4.5 Results

Enter the determined measured and calculated values into the following results table.

3.4.5.1 Results Table

Three-phase Squirrel Cage Induction Motor 1.0								
Measurement	M/Nm	0.6	1.2	1.8	2.4	3.0	3.6	4.2
	n/min^{-1}							
	I_1/A							
	cos φ							
	$P_{1\ phase}$/W							
Calculation	P_1/W							
	P_2/W							
	cos φ							
	η							
	s/%							

	M/Nm	4.8	5.4	6.0	6.6	7.2	7.8	8.4
Measurement	n/min^{-1}							
	I_1/A							
	cos φ							
	$P_{1\ phase}/W$							
Calculation	P_1/W							
	P_2/W							
	cos φ							
	η							
	s/%							

3.4.6Calculation

Calculate the values required for completion of the result table and enter them into the table. Show the calculation steps for measurement at load with nominal torque.

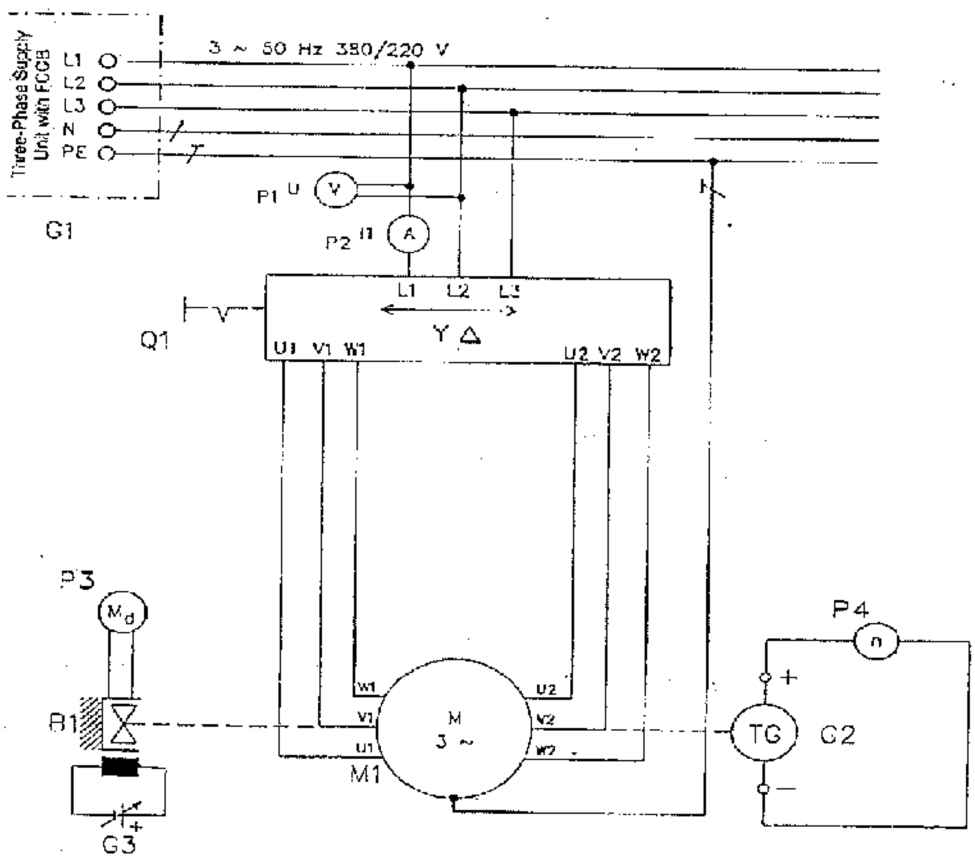
3.4.7 Load Characteristics

Using the measured and calculated values, plot the curves for the three-phase squirrel cage induction motor. Plot a vertical line for the nominal torque on the diagram.

3.5 Run-up Characteristics M = f (n), I = f (n) for Star and Delta Connection

3.5.1 Measurement of the Run-up Characteristics of a Three-phase Squirrel Cage Induction Motor in Star and Delta Configuration

3.5.1.1 Circuit Diagram



3.5.1.2Circuit Assembly

Assemble the measurement circuit according to the diagram for determining the run-up characteristics

3.5.1.3 Experiment Procedure

After the teacher has checked ad approved the circuit, put the circuit into operation. Make sure that the brake is completely open.

Note: At no-load there is an indication on the meter which represents the residual friction from the brake and the no-load torque of the machine. It must be taken into account when making exact measurements.
After it has run-up, break the motor from no-load operation to standstill. Measure the corresponding speed, torque and stator current in star and delta connection.

Setting of the Magnetic Powder Brake on the Control Unit

Before operation set the control unit as follows:

Control Unit	**1.0**
Speed Range Switch "min^{-1}"	**3000**
Torque range Switch "Nm"	**10**
Operation Mode Switch	**MAN1**

Put the motor into operation.
Complete the measuring as quickly as possible, because the rated motor current is exceeded under load and the motor is therefore at times heavily overloaded, which leads to disengagement to the brake operation via a thermal switch.

3.5.1.4 Results

Enter the measured values into the results table!

3.5.1.4.1 Results Table M = f (n), I = f (n) in Star Connection

Short-circuit Motor 1.0 M/Nm												
M(Nm)	**0.5**	..	...	...	...	....	....	....	....	....	....	**9.0**
n(min^{-1})												
I1(A)												

3.5.1.4.2 Results Table M = f (n), I = f (n) in Delta Connection

Short-circuit Motor 1.0 M/Nm												
M(Nm)	**0.5**	..	...	...	...	....	....	....	....	....	....	**8.5**
n(min^{-1})												
I1(A)												

3.5.1.5 Run-up Characteristics

Plot the measured values of the three-phase short circuit motor on a graph.
Draw the nominal current and nominal torque a s perpendicular lines on the diagram.