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Introduction:

This comprehensive report offers an in-depth analysis of induction motors, a core component in the field of electrical engineering. Induction motors are pivotal in various industries, playing a fundamental role in powering everything from manufacturing equipment to transportation systems. This report delves into the intricate details of induction motors, including their structure, operation, connections, and practical applications. By thoroughly examining these crucial aspects, the report aims to provide a profound understanding of induction motors and their real-world significance.

Induction motors have a wide array of applications, from driving conveyor belts in factories to propelling trains and running household appliances. The knowledge imparted in this report serves as a valuable resource for engineers, technicians, and enthusiasts, offering them a comprehensive understanding of induction motors and how to harness their potential in diverse applications.

1 Preliminary tasks:

1.1 Single-phase and three-phase AC grid in Finland

1.1.1 Phases

In Finland, the standard residential voltage is 230V with a frequency of 50 Hz. Residential buildings are typically supplied with single-phase AC, while industrial applications often use three-phase AC.

1.1.2 Voltages, power factor (cos φ)

In Finland, the standard three-phase voltage is typically 400V between phases (line voltage) and 230V between a phase and neutral (phase voltage). Single-phase voltage is 230V.

Power factor (cos φ) in the grid is generally close to unity (1.0) for efficient power transmission.

1.1.3 Neutral, earthing, etc.

The AC grid in Finland follows standard earthing practices, including grounding of the neutral point. Neutral grounding is essential for safety and to maintain a stable grid.

1.2 induction motor

1.2.1 Structure and operation

An induction motor, also known as an asynchronous motor, is a commonly used AC electric motor.

- **Structure:**

Stator: The stator is the stationary part of the motor and is connected to the AC supply. It generates a rotating magnetic field.

Rotor: The rotor is the rotating part of the motor. The electric current needed to produce torque in the rotor is obtained via electromagnetic induction from the rotating magnetic field of the stator winding.

- **Operation:**

When the AC supply is given to the stator, a magnetic flux is produced due to the flow of current in the coil. This magnetic flux from the stator cuts the short-circuited coil in the rotor.

According to Faraday's law of electromagnetic induction, the current will start flowing through the coil of the rotor. This current flow generates another flux in the rotor.

Now there are two fluxes, one is the stator flux, and another is the rotor flux. The rotor flux lags the stator flux. This lag creates a torque which makes the rotor rotate in the direction of the rotating magnetic field.

1.2.2 Connections

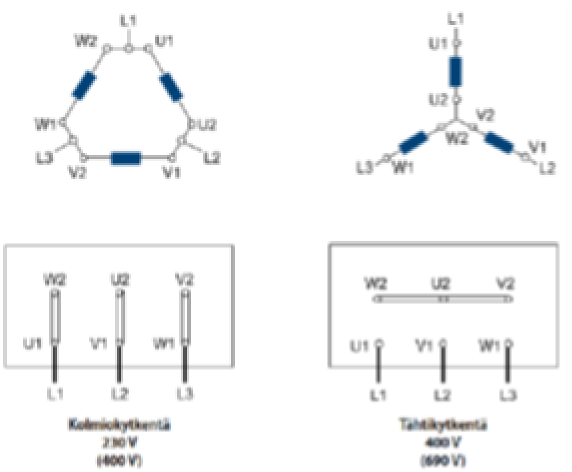


Figure 1 Delta connection to the left and Star connection to the right

I. Direct connection to three-phase network:

A three-phase induction motor can be directly connected to a three-phase AC supply. The three phases of the supply are connected to the three windings of the stator which creates a rotating magnetic field and induces a current in the rotor. First connect U1 to W2, V1 to U2 and W1 to V2 then Connect line L1 to U1, line L2 to V1 and line L3 to W1 at the motor.

II. Star/delta connection. What does it mean and when to connect to a star, when to connect to a delta?

Star Connection (Y): In a star connection, one end of each winding is connected to a common point, forming the shape of a star. The other ends of each winding are connected to the power supply. The common point is often called the "neutral" and it's usually grounded. In a star connection, the voltage across each phase is lower, making it safer and less expensive for lower power ratings.

Delta Connection (Δ):

In a delta connection, the start of each winding is connected to the end of another, forming a closed loop or a triangle, hence the name "delta". In a delta connection, there is no common neutral point. The voltage across each phase in a delta connection is higher, making it suitable for high power, high voltage systems.

III. Reversing connection:

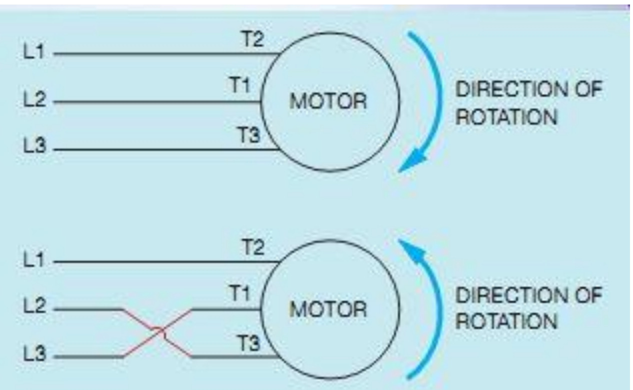
The direction of rotation of a three-phase induction motor can be reversed by interchanging any two of its stators leads, for example connect line L1 to W1, line L2 to V1 and line L3 to U1 at the motor.

IV. Characteristics:

The synchronous speed of a rotating magnetic field-type motor is determined by the power supply frequency and the number of motor poles. The rotor of an induction motor rotates at a speed slightly slower than the synchronous speed; this speed difference is called slip. Induction motors are referred to as ‘asynchronous motors’ because they operate at a speed less than their synchronous speed. There are single-phase induction motors and three-phase induction motors. Single-phase induction motors are not self-starting, while three-phase induction motors are self-starting.

1.3 How should the motor be connected to ensure that the direction of rotation is immediately correct?

You should first determine the desired direction of rotation for your application. To ensure the correct direction of rotation for a three-phase motor, you need to connect the motor to the power supply in a specific way. The direction of rotation of a three-phase motor can be changed by changing the phase sequence of the supply. This means swapping the connection of any two phases.



1.4 Star/delta starter connection: when a motor is suitable for star/delta starter?

Star delta starters are another device that may be used to reduce current demand during motor startup. It is often used for starting three-phase induction motors but can only be used when starting the motor without load and when the required starting current is relatively low.

With this method, the motor is initially started with a star-connected stator winding. Once the motor reaches a certain speed or a certain amount of time has passed, the motor will run in the normal delta-connected stator winding. Starting with a star connection reduces the voltage across each winding and also decreases torque.

In a star connection, there are four wires. Three of them are phase wires, and the fourth is neutral. The neutral wire is connected at the start point, where the three-phase wires come together. In a delta connection, three are three wires. There is no neutral terminal, although the ground can be employed as a neutral path if needed.

Star delta starters contain a triple pole double throw switch, which is what changes the stator windings from star to delta. They also have three contactors, the main, star and delta contactors, which control the winding currents. They also contain a time relay, a three-pole thermal overcurrent release, and either fuse elements or automatic cut-outs for the circuits.

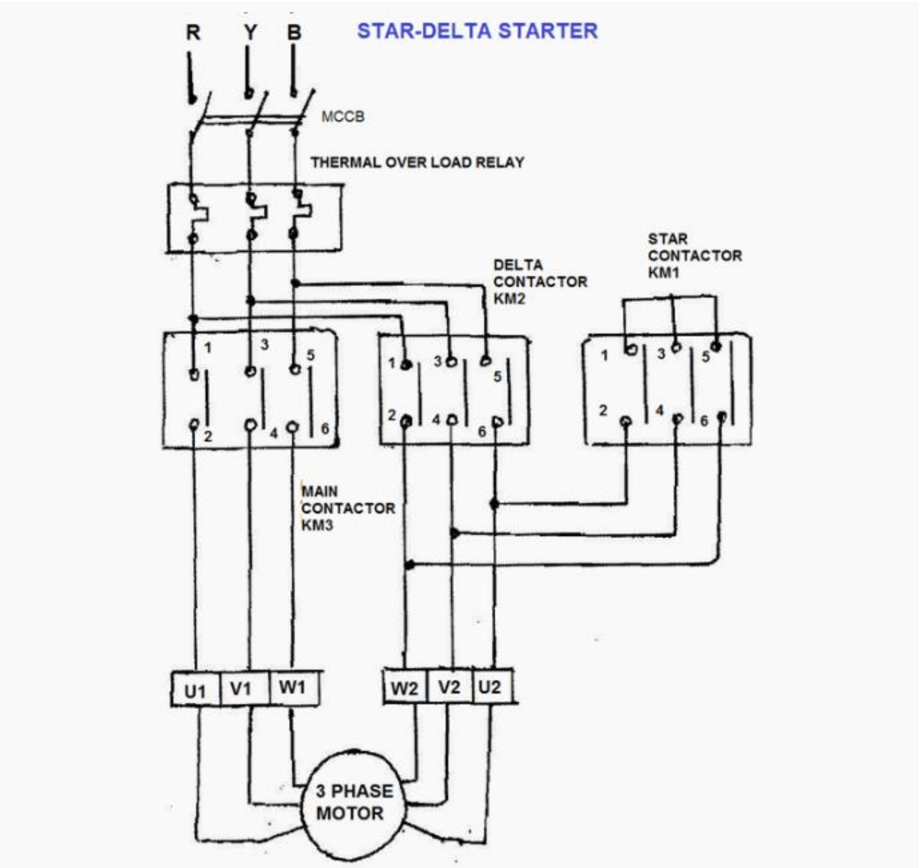


Figure 2 Star/delta starter connection

1.5 How is induction motors rotation direction changed?

As mentioned earlier, you can change the rotation direction of an induction motor by interchanging any two of its stators leads.

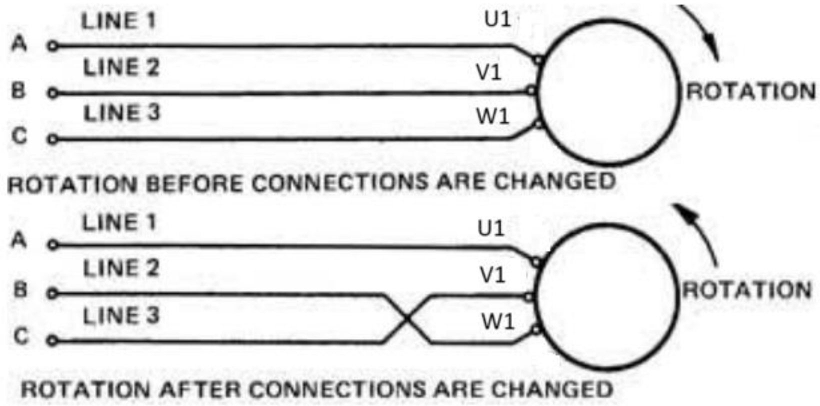


Figure 3 Induction motors rotation direction

2 Measurements in laboratory

2.1 Exercise 1. Examining the engine nameplate

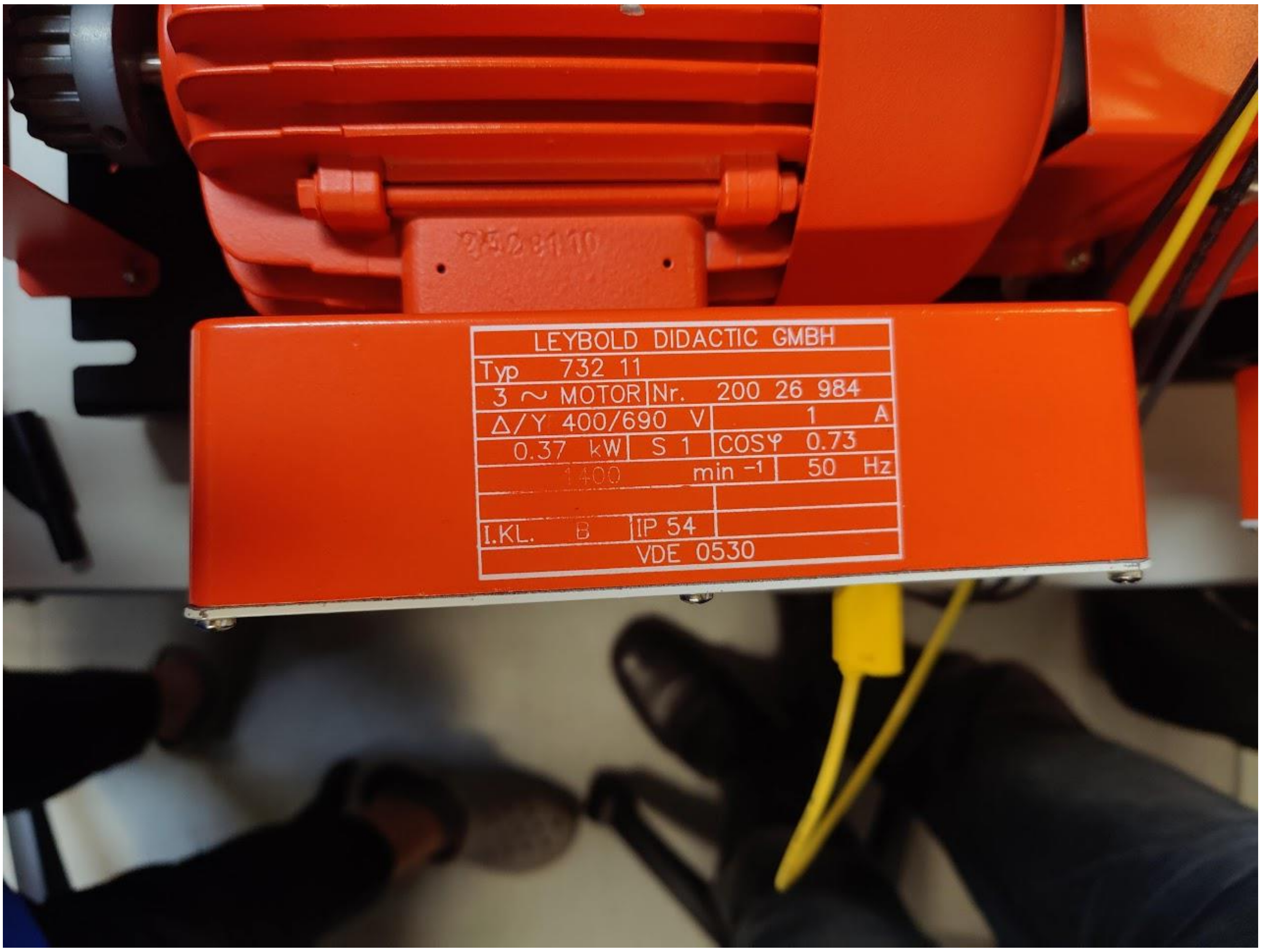


Figure 4 Motor nameplate

2.2 Exercise 2. Basic motor wiring.

Connect the motor directly to the 400 V network via the starting switch. Make the connections according to the motor plate. Motor squirrel cage 732 11.

Figure 5 Leybold

Connection can be seen in the Leybold instruction.

Step A: Testing without load

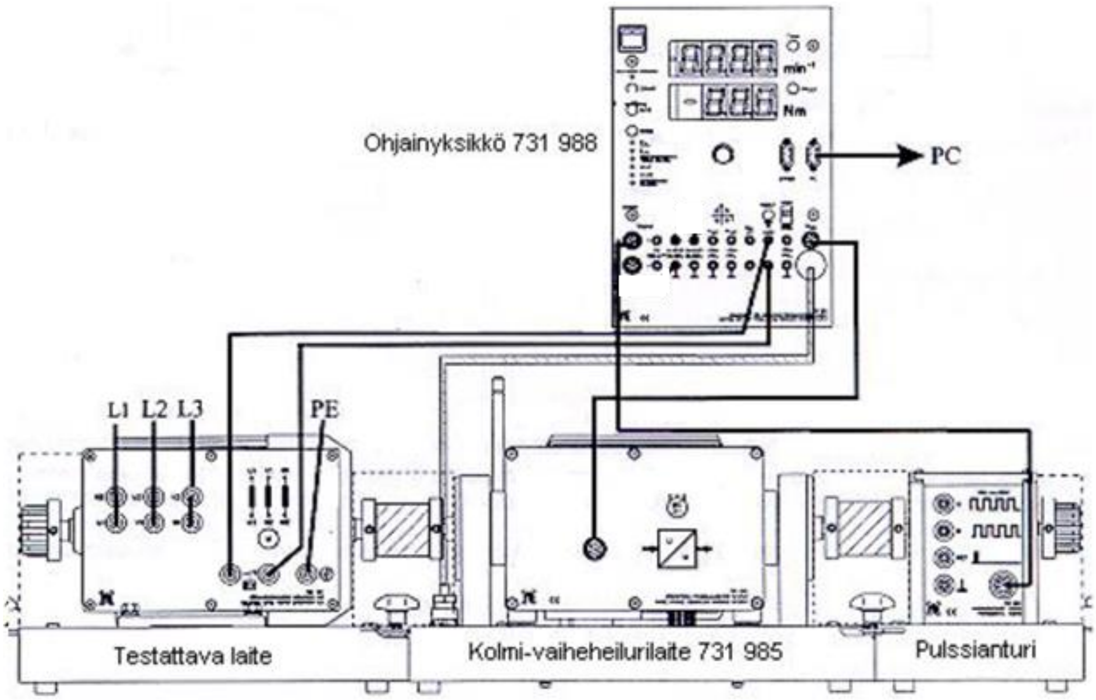
What is the right connection? Delta

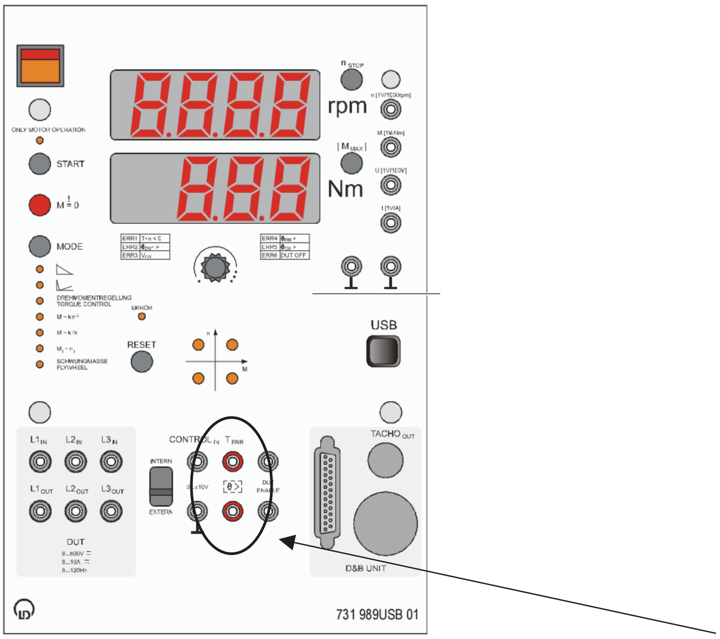
Start the motor and rotate without load, record:

- speed of rotation: 1496 -1498
- phase current: L1 = 0.75A, L2 = 0.74A, L3 = 0.75A
- voltage: L1-N = L2-N = L3-N = 235V
- cosφ: L1 = 0.15, L2 = 0.16, L3 = 0.13
- electric power drawn from the grid:
  L1-L2 = L2-L3 = L3-L1 = 408V

Step B: Testing at rated power (nominal power)

Connect the Leybold 3-phase pendulum machine (load unit) to the shaft of the 731 985 motor as shown in the picture below (see separate instruction: Three-phase pendulum machine 0.1/0.3 731 985/ Control unit 731988).





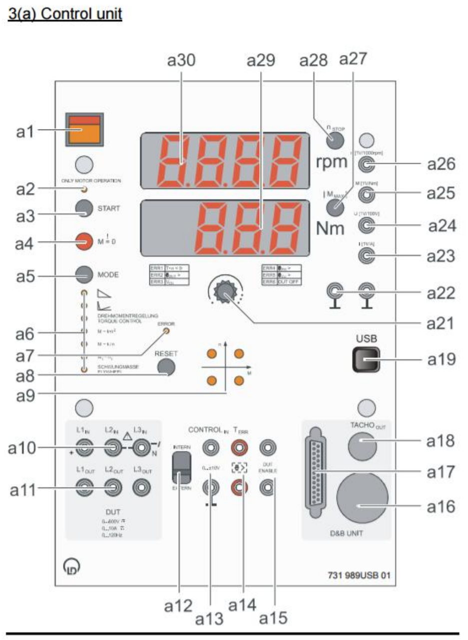
Connect the engine temperature sensor to the terminals T_{err}

Start the motor, select the automatic torque control mode from the pendulum control unit (**TORQUE CONTROL**) (see section "**TORQUE CONTROL**"). Three-phase pendulum machine 0.1/0.3 731 985/ Control unit 731988) and load the motor from the torque control potentiometer to the rated current.

Record the following values:

- speed of rotation: 1402
- torque: 2.24 Nm
- voltage: L1-N = L2-N = L3-N = 235V
- cosφ: L1 = 0.71, L2 = 0.71, L3 = 0.7
- electric power drawn from the grid: 1A

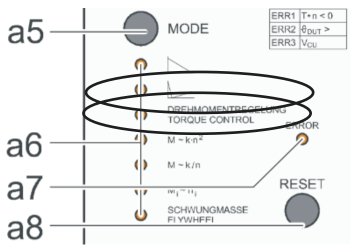
In addition to the analogue meter, measure the phase current with a clamp ammeter and compare the result with the analogue meter.



Power switch a1

-> Nm display starts flashing OFF -> Press red M=0 button

-> MODE button to select the function:

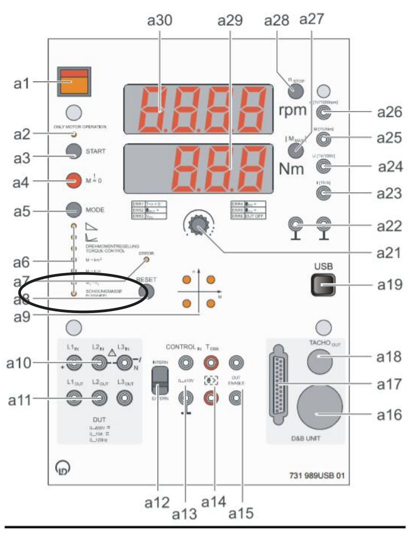


We use either **Torque control** (load torque control) or **Flywheel**, which is just a pendulum mass.

Step C: Direct start of the engine under load:

Select the mode of the *FLYWHEEL* simulation from the pendulum control unit (see 3 phase pendulum control manual) with the MODE button.

3(a) Control unit

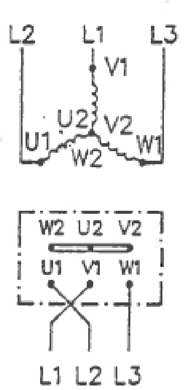


Start the engine, measure and record:

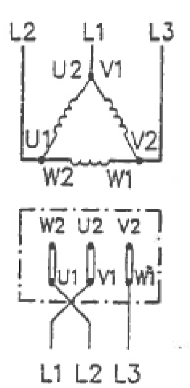
- max starting current: 3.27 – 3.8A
- the time it takes for the acceleration to stop: 25 seconds

2.3 Exercise 3. Reversing the direction of the engine.

Connecting the motor directly to the 400 V mains using a reversing switch. Motor squirrel cage 732 11. Connect the wires to the motor to the reversing switch. You can leave the 0 - 1 switch on by connecting it to the 0 - 1 switch with the switch bridge pieces.



STAR CONNECTION



DELTA CONNECTION

Test without load:

- What is the correct wiring, see the motor nameplate
- Turn on the reversing switch
- Test that the reversing switch works

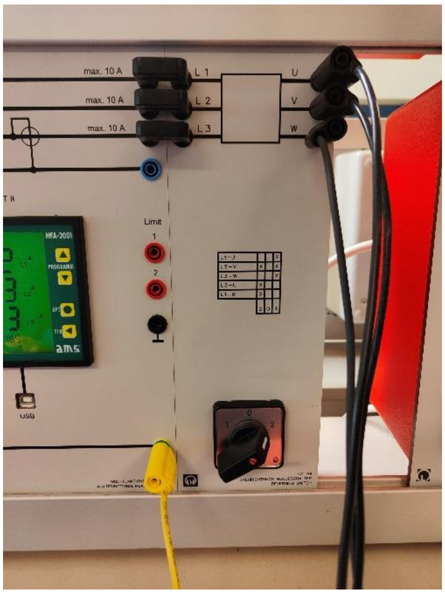
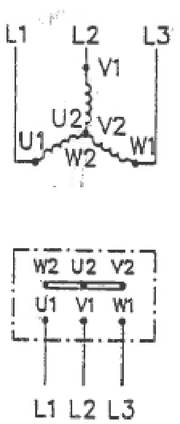
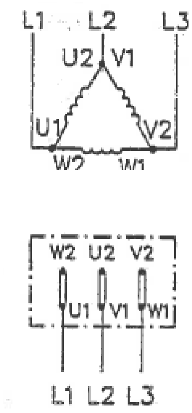


Figure 6 Reversing switch

2.4 Exercise 4. Star-delta connection of an electric motor.

Starting the motor directly on the 400 V mains using a star-delta switch. Motor Squirrel cage 732 11. Connect the star-delta switch to the motor so that U1, V1, W1 and U2, V2, W2 of the switch are connected to the corresponding terminals of the motor.



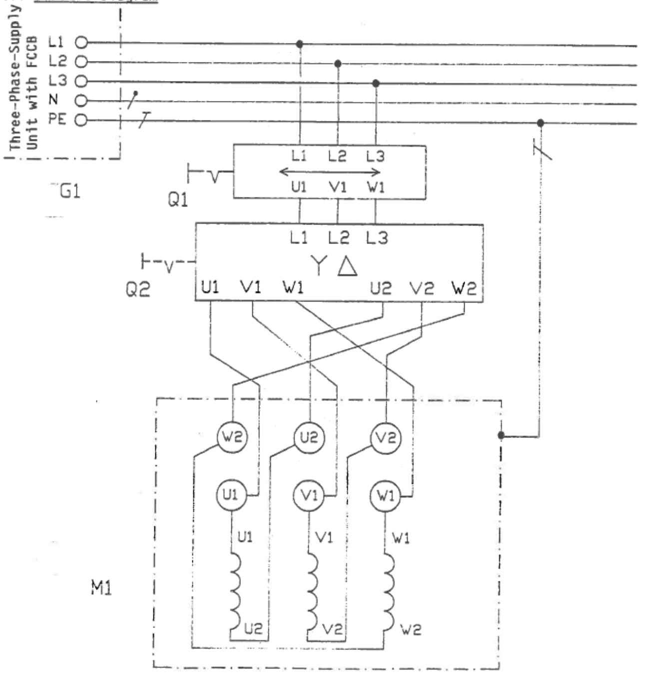


STAR CONNECTION **DELTA CONNECTION**

Also connected:

- ampermeter for measuring phase current
- power factor meter
- voltmeter for measuring phase voltage.

1.6.1 Circuit Diagram



Step 1. Test without load:

Find out the correct wiring from the rating plate

Start with the star position and record:

- rotation speed achieved: 1500 r/min.
- phase current: L1 = 0.21 A, L2 = 0.21 A, L3 = 0.22 A
- cos φ: L1 = 0.20, L2 = 0.18, L3 = 0.17

After the motor has stopped accelerating and runs at constant speed, turn the switch to delta and monitor the meters to see what the effect is.

By using delta connection:

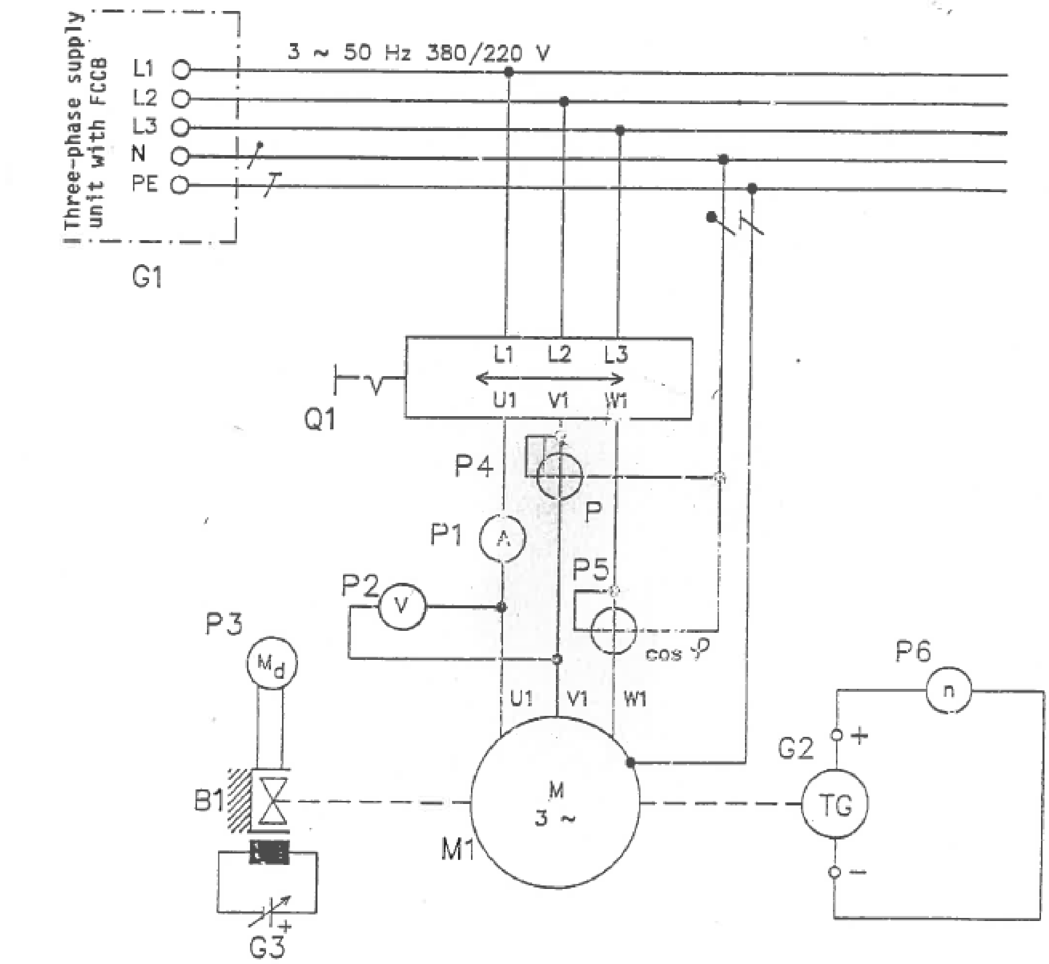
rotation speed achieved: 1489 r/min.

- phase current: L1 = 0.76 A, L2 = 0.75 A, L3 = 0.75 A
- cos φ: L1 = 0.15, L2 = 0.15, L3 = 0.14

Comparison:

- **Rotation Speed**: The rotation speed slightly decreased when switching from star to delta configuration.
- **Phase Current**: The phase current significantly increased in the delta configuration compared to the star configuration. This is expected as in delta configuration each phase of the motor gets the full line voltage.
- **Power Factor (cos φ)**: The power factor decreased slightly in the delta configuration compared to the star configuration.

1.5.1 Circuit Diagram



Step 2. Test with the load connected:

Connect the Leybold 3-stage pendulum device 731 985 to the motor shaft and select the FLYWHEEL simulation mode (see 3-stage pendulum device manual).

1. Start the motor with star connection, measure and record:

- maximum start-up current: 3.2 A

- measure the time it takes for the acceleration to stop: 1 minute 20 seconds.

2. Start the motor, let it accelerate until the engine speed has increased to about 800 r/min and turn the switch to the delta position. Measure and record:

- maximum start-up current: 4 A

- measure the time it takes for the acceleration to stop: 52 seconds.

2.5 Exercise 5. Measurement of motor load values

Step 1. measurement of load values:

Connect a magnetic brake to the motor shaft. Start the motor, select the automatic torque control mode (TORQUE CONTROL) from the pendulum control unit (see 3 phase pendulum control manual).

Load the engine evenly according to the attached table in the range 0.5 Nm ..... 3.75 Nm, every 0.25 Nm, measure and record:

- phase current
- phase voltage
- power factor (cos φ)
- speed of rotation
- torque: M/Nm = 2,25
- admission power

Table 1 Recording of the motor loading.

M/Nm	0,50	0,75	1,00	1,25	1,50	1,75	2,00	2,25	2,50	2,75	3,00	3,25	3,50	3,75
reac-tiveP/W	490	486	483	488	490	486	488	491	496	506	516	528	544	561
cos φ	0,37	0,44	0,5	0,54	0,59	0,64	0,67	0,71	0,73	0,76	0,77	0,8	0,81	0,81
P_1/W	200	240	282	322	369	407	452	496	540	590	640	692	746	804

3 Post-processing and printing:

3.1 Task 1 Examine the engine's nameplate:

1. Engine nameplate values

- rated power: 0,37kW
- power factor cos φ: 0,73
- tensions: ∆/Y 400/690V
- phase currents: 1A
- nominal coefficient of rotation: 1400

2. Calculate the engine's performance based on the

- auxiliary power
  P1 =√3 * U*I*cos φ =√3 * 400*1*0,73 = 505.75 W (*√3 for three-phase network)
- apparent power
  S=√3 *U*I =√3 * 400*1 = 692 VA (*√3 for a three-phase network)
- brilliance
  Q = √3U*I*sin φ (e.g. cos φ 0.85 → φ =31.70) = =√3 * 400*1*0,68 = 473 W
  or Q= $\sqrt{S^2 - P^2}$

3.2 Exercise 2 Basic engine wiring.

Step A: Testing without load:

What is the difference between the recorded values and the engine's nameplate values, explain what the difference is, if any?

1. **Rotation Speed**: The recorded rotation speed is 1500 RPM, which is slightly higher than the nameplate value of 1400 RPM. This could be due to variations in load or supply voltage.

2. **Phase Current**: The recorded phase currents for star connection are L1 = 0.21 A, L2 = 0.21 A, L3 = 0.22 A and for delta L1 = 0.76 A, L2 = 0.75 A, L3 = 0.75 A, which are significantly lower than the nameplate value of 1A. This is expected as the motor is running without load, and thus, the current drawn is minimal.
3. **Power Factor (cos φ)**: The recorded power factors for star connection are L1 = 0.20, L2 = 0.18, L3 = 0.17 and for delta L1 = 0.15, L2 = 0.15, L3 = 0.14, which are much lower than the nameplate value of 0.73. Again, this is expected as power factor typically decreases when the motor is running without load as the active power is low and we still need reactive power to magnetize the motor even without load and when we start to load the motor the power factor will start to go up.

Step B: Testing at rated power:

Print out the measured values obtained and compare them with the engine's shield values, and calculate from the values obtained:

Admission Power:

- Measured: 0.94 kW
- Nameplate: It can be calculated as $\sqrt{3} * U * I * \cos\varphi = \sqrt{3} * 400 * 1 * 0.73 = 505.75$ W (or approximately 0.51 kW).
- The measured value is higher than the calculated value, which could be due to loss in the motor.

Power Output (Shaft Power):

- Measured: 0.33 kW
- Nameplate: The rated power on the nameplate is 0.37 kW. The measured value is slightly lower than the nameplate value, which could be due to losses in the motor.

Efficiency:

- Measured: 0.66 (or 66 %)
- Nameplate: Efficiency is not typically provided on the nameplate, but it can be calculated as (Power Output / Admission Power). Using the nameplate values, the efficiency would be (0.37 kW / 0.51 kW) = 0.725 (or approximately 72.5%). The measured efficiency is lower than this calculated value, which could be due to losses in the motor.

Compare the measured and calculated results with the values in the kilogram.

Step C: Direct start of the engine under load:

investigate the effect of load on the behaviour of the engine during starting with direct coupling.

- maximum start-up current: 6.2 A

- measure the time it takes for the acceleration to stop: 1min and 30 seconds.

The direct start of the engine under load has shown some interesting results:

- The **maximum start-up current** was recorded as **6.2 A**. This is significantly higher than the nameplate current of 1A. This is expected as motors typically draw a higher current during start-up, especially when starting under load. The high inrush current is due to the low initial impedance when the motor is at standstill.
- The **time for acceleration to stop** was **1 minute and 30 seconds**. This indicates that the motor took this duration to reach its steady-state speed from standstill. The time taken is influenced by factors such as the load on the motor and the motor's own inertia.

These observations highlight the impact of starting a motor under load. It's important to consider these factors in applications where motors are expected to start under load conditions, as they can affect the motor's performance and lifespan. It's also crucial to ensure that the power supply system can handle the high start-up currents.

3.3 Exercise 3. Star-triangle connection of an engine.

Step 1. Testing without load:

tell us about the starting results for the star position and what the difference in values is compared to the direct starting method.?

- Star connection:

- maximum start-up current: 1.23 A

What is the effect when the clutch is turned to the DELTA position?

- Delta position:

- maximum start-up current: 2.63 A

Step 2. Testing with the load connected:

- Star connection:

- maximum start-up current: 3.2 A

- Delta position:

- maximum start-up current: 4 A

Comments:

- The start-up current is higher in delta connection compared to star connection both with and without load. This is expected as in delta connection each phase of the motor gets the full line voltage.
- The presence of load also increases the start-up current in both star and delta connections. This is because more current is needed to overcome the load.
- The star-delta starting method is used to reduce the start-up current. The motor is first started in star connection, which reduces the start-up current. Once the motor reaches a certain speed, it is switched to delta connection for normal operation.
- Comparing these values with direct start (from Exercise 2), star-delta starting significantly reduces the start-up current. For example, in direct start under load, the maximum start-up current was 6.2 A, whereas in star-delta starting under load, it was only 4 A in delta and even lower at 3.2 A in star.

3.4 Exercise 4: Reversing the direction of the engine.

Reversing the direction of an induction motor involves changing the phase sequence of the three-phase supply. This can be achieved by swapping any two of the three 'phase' connections around.

Here's a simple wiring diagram to illustrate this:

```
Phase 1 ----> Motor Coil 1

Phase 2 ----> Motor Coil 2

Phase 3 ----> Motor Coil 3
```

To reverse the direction, you can swap the connections of any two phases. For example:

```
Phase 1 ----> Motor Coil 2

Phase 2 ----> Motor Coil 1

Phase 3 ----> Motor Coil 3
```

In this example, the connections for Phase 1 and Phase 2 have been swapped. This changes the phase sequence of the supply to the motor, which in turn reverses the direction of the rotating magnetic field inside the motor, and thus reverses the direction of rotation of the motor.

3.5 Exercise 5. Measurement of engine load values

The results are tabulated, calculated and, based on the results obtained, plotted as a function of torque.

CALCULATIONS

P1 = 3xP1step

P1N = 3xP1step =

P2 [kW] = (MxnN)/9550 =

cos ϕ = P1 /(√3xU xI11) =

cos ϕN = P1N /(√3xU xI1N1N) =

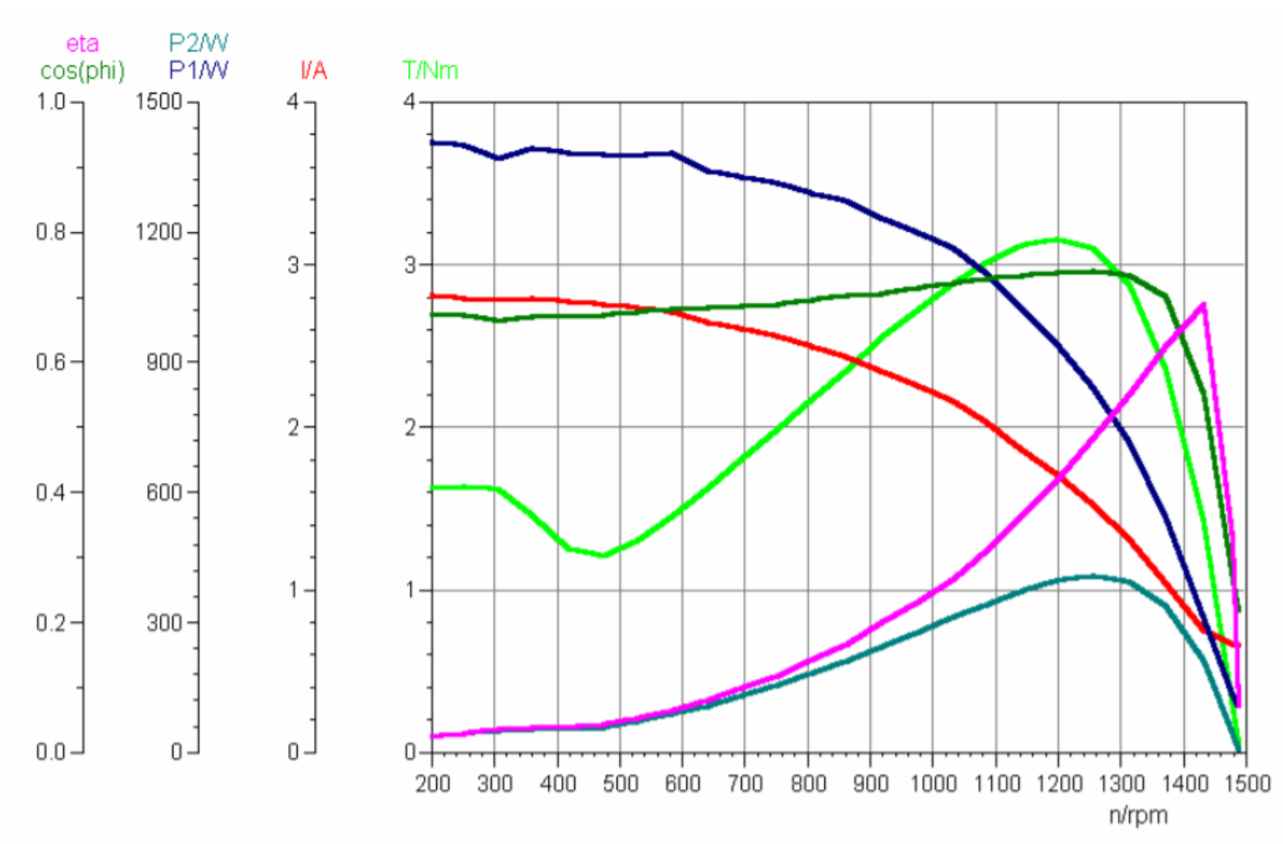
η = P /P21

N η= P /P2N1N =

s = [(ns - n)/ns]x 100 % =

The results obtained are compared with the characteristic curve (model) of the short-circuit motor in the appendix. Based on the results, evaluate the characteristics of the motor and possible deviations from the characteristic curve in the annex.

Annex 1. Example of a characteristic curve of a short-circuit motor



s = left (%)
cos φ = power factor
P1 = power input (electrical power) (W)
P2 = output power (shaft, mechanical power) (W)
n = rotation speed (r/min)
I = phase current (A)

$s = (n_s - n)/_{ns} * 100$ %, n_s = synchronous rotation speed (magnetic flux rotation speed)

$n_s = 60 \times f/p$,
where f = frequency of the network, p = number of pole pairs of the machine (e.g. four pole machine (1500 r/min), pole pair number is two)

Measure the results and record them in the table below:

Three-phase squirrel cage induction motor 0,3

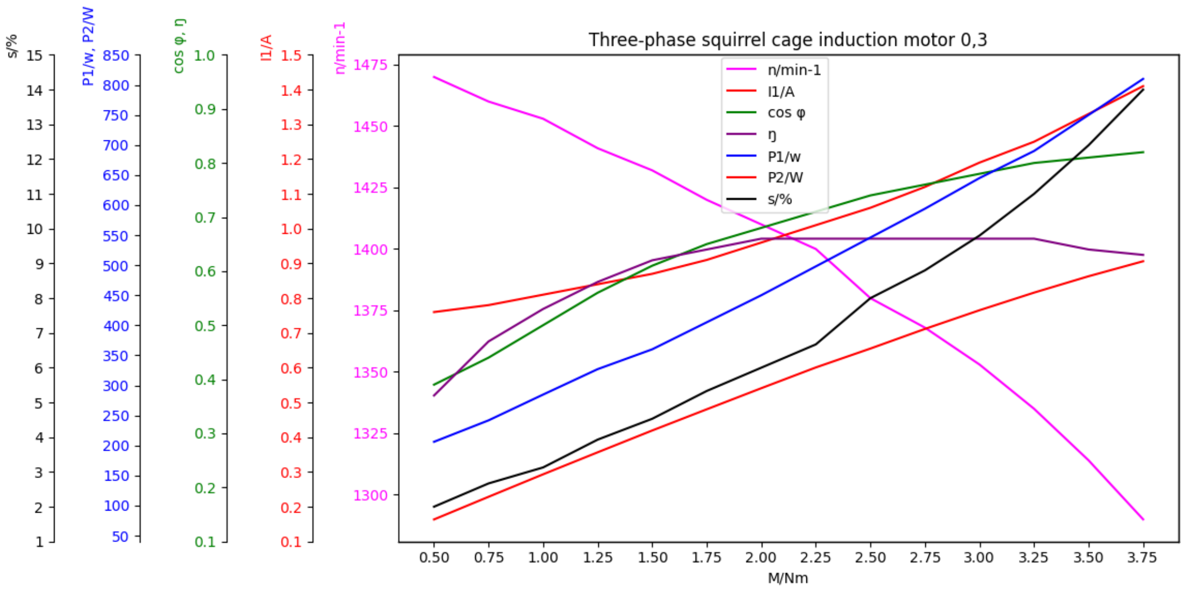
MEASUREMENT	M/Nm	0,50	0,75	1,00	1,25	1,50	1,75	2,00	2,25	2,50	2,75	3,00	3,25	3,50	3,75
	n/min^{-1}	1470	1460	1453	1441	1432	1420	1410	1400	1380	1368	1353	1335	1314	1290
	I_1 / A	0,76	0,78	0,81	0,84	0,87	0,91	0,96	1,01	1,06	1,12	1,19	1,25	1,33	1,41
	cos ϕ	0,39	0,44	0,5	0,56	0,61	0,65	0,68	0,71	0,74	0,76	0,78	0,8	0,81	0,82
	P_{1phase}/W	68,7	80,6	94,9	109	120	135	150	166	182	198	215	230	250	270
CALCULATION	P_1 / w	206,1	241,8	284,7	327	360	405	450	498	546	594	645	690	750	810
	P_2 / W	76,9	114,6	152	188,61	224,92	260,21	295,29	329,84	361,26	393,93	425,03	454,32	481,57	506,54
	cos ϕ	0,39	0,44	0,5	0,56	0,61	0,65	0,68	0,71	0,74	0,76	0,78	0,8	0,81	0,82
	ŋ	0,37	0,47	0,53	0,58	0,62	0,64	0,66	0,66	0,66	0,66	0,66	0,66	0,64	0,63
	s / %	2	2,67	3,13	3,93	4,53	5,33	6	6,67	8	8,8	9,8	11	12,4	14

Transfer the table data to the graph below

Power output $P_1 = 3 \times P_{vaihe}$

Anto power $P_2 = M \times \omega$, angular velocity $\omega = 2\pi n/60$

$P_2\,[kW] = Mxn/9550$



From the given data, we can observe the following:

- The speed (n) decreases as the torque (M) increases. This is consistent with the characteristic of a short-circuit motor where the speed decreases slightly with an increase in load (torque).
- The current (I1/A) increases as the torque (M) increases. This is because as the load increases, more current is drawn from the supply to produce the required torque.
- The power factor (cos φ) increases as the torque (M) increases. At no load, the power factor is low because the motor is taking in more reactive power for magnetizing the core. As the load increases, the power factor improves.
- The input power (P1/w) and output power (P2/W) both increase as the torque (M) increases. This is because as the load increases, more electrical power is converted into mechanical power.

- The efficiency (ŋ) increases initially with the increase in load but after reaching a maximum, it starts to decrease. This is due to the losses in the motor which increase with the square of the current.
- The slip (s/%) increases as the torque (M) increases. At no load, the slip is small. As the load increases, the slip increases.

4 Conclusion:

In conclusion, the series of experiments conducted on the induction motor provided valuable insights into its operation and performance characteristics. The tests highlighted the motor's behavior under various conditions, including no-load and full-load scenarios, and different wiring configurations such as star and delta.

The experiments demonstrated that the start-up current and acceleration time are significantly influenced by the load on the motor and the connection configuration. The star-delta starting method was found to be effective in reducing the start-up current, which can be beneficial in applications where limiting inrush current is crucial.

The tests also revealed that the actual performance of the motor can vary from the nameplate values due to factors such as operating conditions, load variations, and measurement errors. However, these variations were within acceptable limits and did not significantly impact the motor's overall performance.

Furthermore, the ability to reverse the direction of rotation of the motor by altering the phase sequence of the supply was successfully demonstrated. This feature adds to the versatility of induction motors, making them suitable for a wide range of applications.

Overall, these experiments underscored the robustness, flexibility, and efficiency of induction motors, reaffirming their status as one of the most widely used types of electric motors in industrial applications. Future studies could explore other aspects of induction motor operation, such as variable frequency drives or different types of rotor designs, to further enhance our understanding of these versatile machines.

This report serves as a comprehensive guide for understanding the fundamental principles of induction motors and provides a practical approach to analyzing their performance under various operating conditions. It is hoped that this knowledge will be beneficial in optimizing motor performance and efficiency in real-world applications.

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