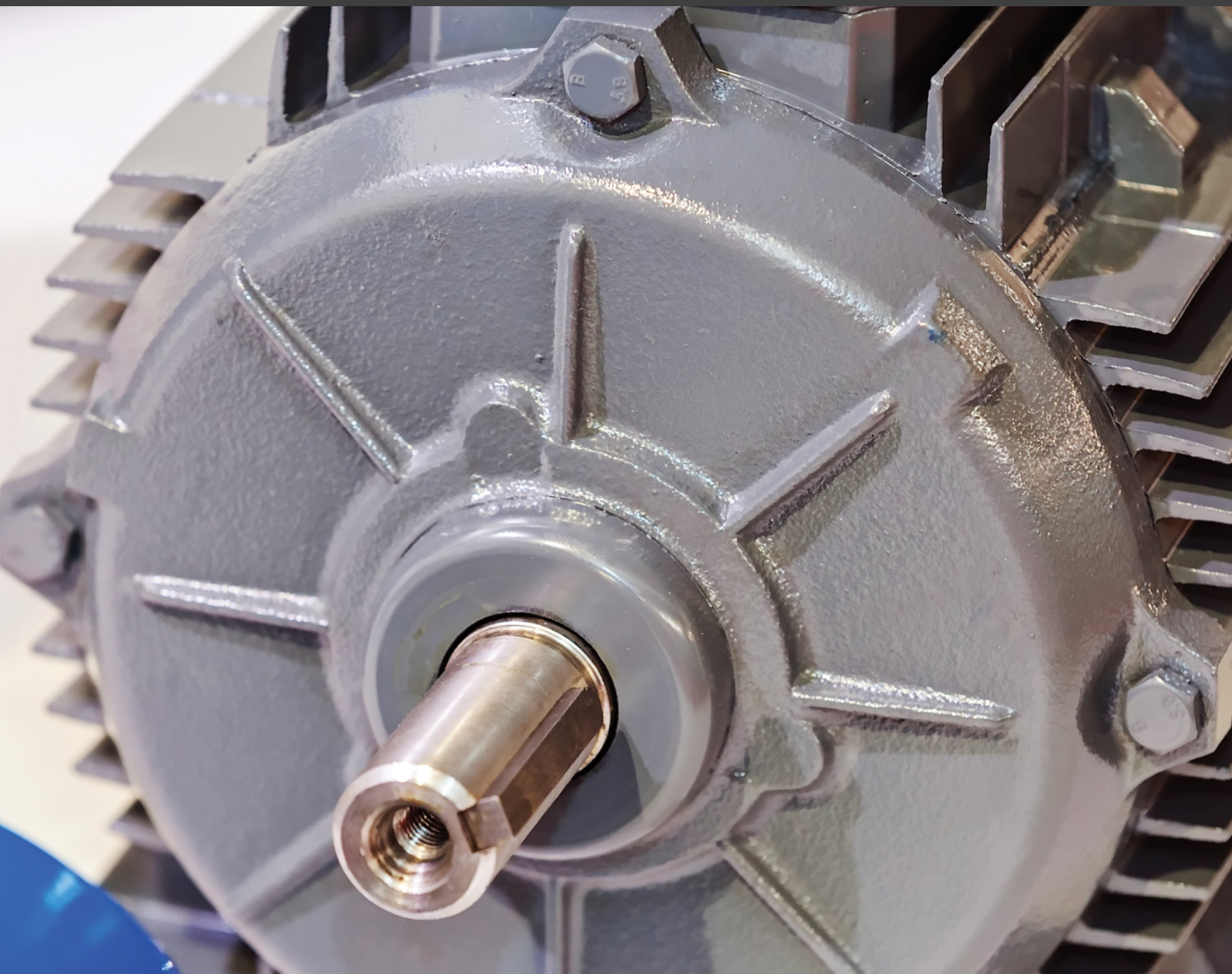


MATRIX | ELECTRICAL MACHINES

Electrical Machines system



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Safety

During the design of this product we have paid considerable attention to the potential risks of studying electric motors. We believe that we have come up with the safest possible design. However there are still some risks that you need to be aware of. This page shows how we have considered each danger. You need to read this and make sure that your students are protected whilst using the equipment.

Electric shock

This is minimal: the output from the control box is limited to 24V AC or DC

The dynamometer is capable of generating DC voltages. At maximum speed, around 3,000 r.p.m., the generated voltage is less than 30VDC.

The control unit will not generate power until a motor is plugged into the dynamometer. This prevents the use of third party motors with the system.

Physical shock

The equipment is heavy. As with other heavy lab. equipment, if a student drops a device on his foot, it could cause considerable damage. You need to decide on the level of responsibility that students take here.

You can reduce risk by having a technician lay the equipment out on benches and ensuring that students are seated at desks whilst using the equipment.

Exposed rotating parts create hazards as hair and clothing can get caught in them. The use of relatively low-power motors reduces the risk. The plastic guard between dynamometer and motor under test means that no rotating parts are exposed..

Caution:

Do not use a PC-based oscilloscope with the equipment.

Earth loop currents may flow between its earth connection and the control box's earth connection.

Calculating torque

Torque is the turning effect of a **force**.

The balance always measures force. This can be related to mass. Force and mass are linked by:

$$\text{Force} = \text{mass} \times \text{acceleration} \text{ or } \mathbf{F = m \times a},$$

where **a** is usually the acceleration due to gravity, 9.81 m/s^2 .

This allows us to calculate the force pressing down on the balance, generated by the dynamometer.

Torque = force x distance from the axis of rotation. It is measured in newton-metres (Nm).

Combining these equations:

$$\text{Torque, } \mathbf{T = m \times a \times r}$$

where, here, **r** is the distance of the pressure point from the centre of the machine.

Putting in the value of **r** for the dynamometer used in this kit:

$$\text{torque (in Nm)} = \text{balance reading (in kg)} \times 9.81 \text{ (m/s}^2\text{)} \times 0.03812 \text{ (m)}.$$

Calculating power

Power is the rate at which energy is delivered and is measured in watts (W).

For a rotating body:

$$\text{Mechanical power} = (2 \times \pi \times \mathbf{n} \times \mathbf{T}) / 60 \quad \text{where } \mathbf{n} \text{ is the speed of the motor in r.p.m.}$$

For a DC motor:

$$\text{Electrical power supplied to the motor} = \mathbf{V_{IN} \times I_{IN}}$$

where **V_{IN}** = input voltage and **I_{IN}** = input current.

For a single phase AC motor:

$$\text{Electrical power supplied to the motor} = \mathbf{V_{IN} \times I_{IN} \times \cos(\Theta)}$$

where **V_{IN}** is the AC rms input voltage, **I_{IN}** is the rms input current

and $\cos(\Theta)$ is the power factor where **Θ** is the phase angle between **V_{IN}** and **I_{IN}**.

For a three phase AC induction motor:

$$\text{Electrical power supplied to the motor} = 3 \times \text{electrical power supplied to one phase}$$

Calculating efficiency

$$\text{Efficiency } (\eta) = (\text{Mechanical power delivered} / \text{Electrical power supplied}) \times 100\%$$

Calculating synchronous speed and slip

Synchronous speed in r.p.m = $(f \times 60) / (\text{number of pairs of poles})$

(Number of pairs of poles relates to how the motor windings are configured:

a 2-pole motor has one pair of poles, a 4-pole motor has two pairs of poles etc.)

$$\text{Slip} = ((\text{synchronous speed} - \text{slip speed}) / \text{synchronous speed}) \times 100\%$$

A three phase supply connected to the stator of an induction machine produces a magnetic field given by the formula:

$$N_s = (f_s/p) \times 60$$

Where f_s = supply frequency and p is the number of pole pairs - in our case 2.

Relationships between three phase star and delta systems

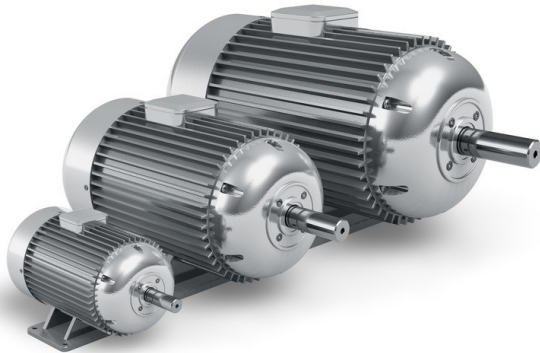
Three phase systems consist of machines connected in star and delta configuration. With U, V and W connections the line voltage is the voltage between any of U, V, W and ground. The phase voltage is the voltage between any two of U, V, W. The line and phase voltage are linked by the equation:

$$V_{\text{line}} = \text{SQRT}(3) \times V_{\text{phase}}$$

Worksheets

Worksheet 1

Getting started



Motors vary hugely in size, shape and technology. Within a family of motors, for example DC motors, the characteristics of the machines are very similar - independent of their physical size and operating voltage.

This section looks at setting up the equipment. Then the testing can begin.

Over to you:

- 1) Connect the control unit to the mains power using the IEC connector. The quad 7-segment display and Power LED should light up.
- 2) Connect the dynamometer to the control unit with the 25 way D-type lead.
- 3) Make sure that the software applications and control unit driver are correctly installed.
- 2) Make sure the packaging strap and sensor block are removed - see Unpacking in the reference section
- 3) Make sure that the rubber 'spider' which buffers the dynamometer and motor under test is in place. The system will work without this - it will just be noisy.
(On first use you might have to push hard!)

When the control box is **not** connected to the PC using the USB lead, the box is in manual mode - the switches and knobs on the front panel determine the control box parameters.

Now you are ready to test the set up .

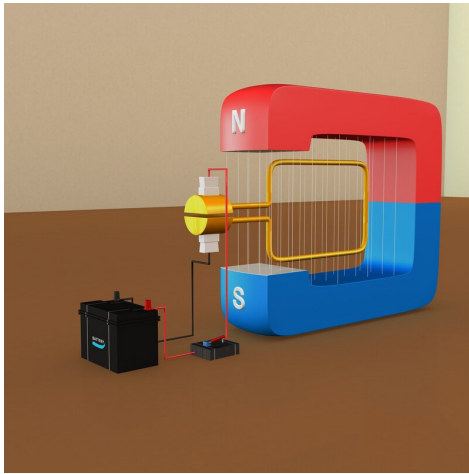
Set up a machine test

- 1) Line up the DC motor in the grooves of the dynamometer test bed.
It should slide in easily. You may have to undo the knurled nuts on the motor bed.
- 3) Make sure the motor and dynamometer couplings are aligned before pushing the motor home.
- 4) As you push home the DC motor into the dynamometer test bed you should hear the safety microswitches in the dynamometer cradle click.
- 5) Tighten the knurled lock nuts to make sure that the DC motor is secured in place.
- 6) Insert the balance and remove **both** protective plastic covers.

You are now ready to start experimenting with the equipment, in manual mode.

Worksheet 2

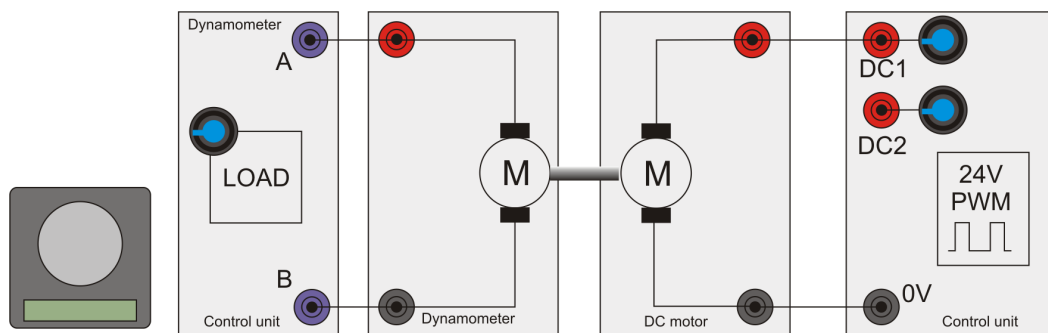
Understanding torque and mass



DC motors use a permanent magnet in the stator and direct current powered windings in the rotor.

A commutator is used to reverse the direction of the current in the rotor to maintain the force on it as the motor turns.

The graphic shows a very simple commutator. In practice, the ring has several splits in it, allowing several rotor circuits to provide more continuous torque.



Over to you:

With the control box in manual mode:

- 1) Put the balance under the swing arm and turn it on.
- 2) Turn the control unit potentiometers to minimum (fully anti-clockwise.)
- 3) Slowly increase the value of DC1 until the DC motor starts to turn.
- 4) Is there a reading on the balance?
If not, swap over the positive and negative connections on the motor to change the direction of rotation.
- 5) With DC1 potentiometer in the middle of its range, note of the balance reading and motor speed in the table below. (The motor speed will vary a little - estimate an average.)
- 6) Turn the DC1 PSU pot to increase the voltage slightly. Measure and record the new balance

reading and speed.

- 7) Referring to the 'Key Relationships' (page 4,) use the readings to calculate the torque for the two settings and record your answers.

Speed	Balance torque

So what?

To change the direction of a DC motor you reverse the electrical connections.

The swinging-arm dynamometer can rotate in either direction. The torque produced is the same for both. When rotating counter-clockwise, pressure is applied to the balance.

When rotating clockwise, the pressure is on the load cell at the back of the dynamometer.

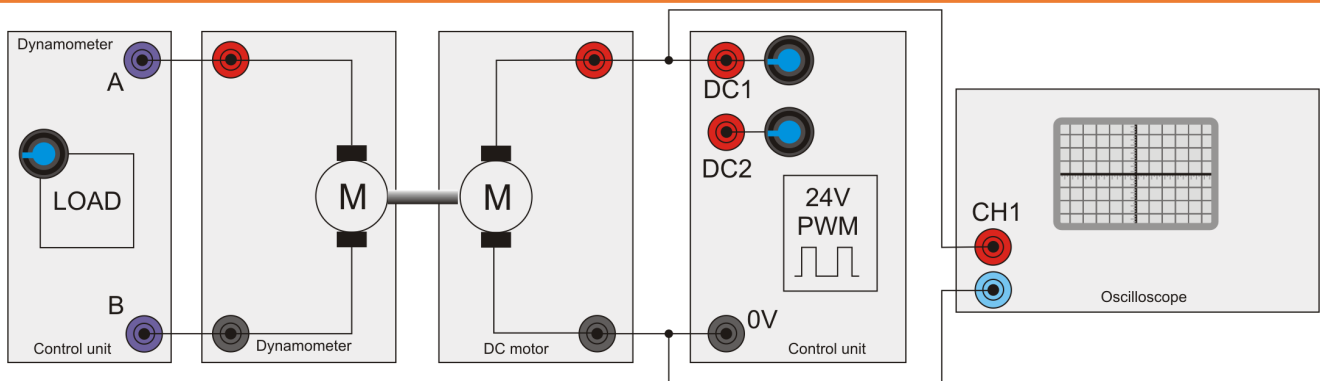
Worksheet 3

Understanding the DC power supply



The permanent magnets occupy a small space in a DC motor compared to the space needed for the windings in motors where the magnetic field is supplied by current-carrying coils. As a result, DC motors can be physically quite small for their power rating.

The food blender in the photograph uses a DC motor.



A motor can be controlled by varying the DC voltage, and hence the power, supplied to it.

Over to you

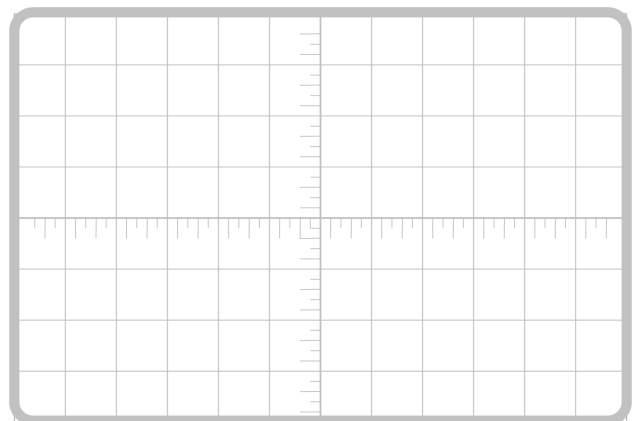
- 1) Adjust the DC1 potentiometer so that it is in about a quarter way of the way round.
- 2) Use an external oscilloscope, not a PC-based one, to look at the signal from DC1.
- 3) Use the upper graph opposite to sketch the waveform of this signal.
- 4) Turn the DC1 potentiometer about three-quarters of the way round and draw the resulting waveform on the lower graph.

So what?

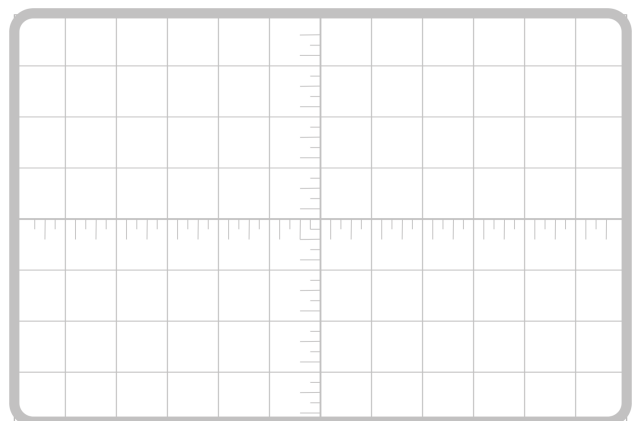
Modern DC motor power supplies do not vary the output in an analogue fashion, but use pulse-width modulation or PWM. In this, the mark : space ratio of the output is varied.

In the control unit, a bank of FET's deliver a PWM signal generated by a computer. This can be used with DC, with single-phase and with three-phase motors.

Do not use a PC-based oscilloscope.



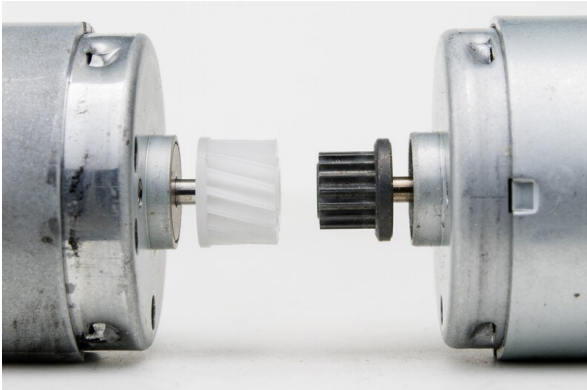
DC1 - one-quarter max.



DC1 - three-quarters max.

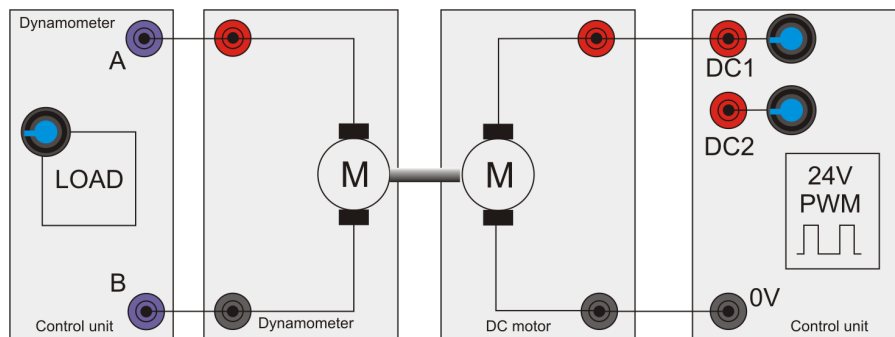
Worksheet 4

DC motor characteristics 1



Different types of motor have different characteristics, such as top speed, torque at different speeds, voltage and current ratings, power output and efficiency.

Photo: these tiny DC motors are used in small handheld devices like toys.



Over to you:

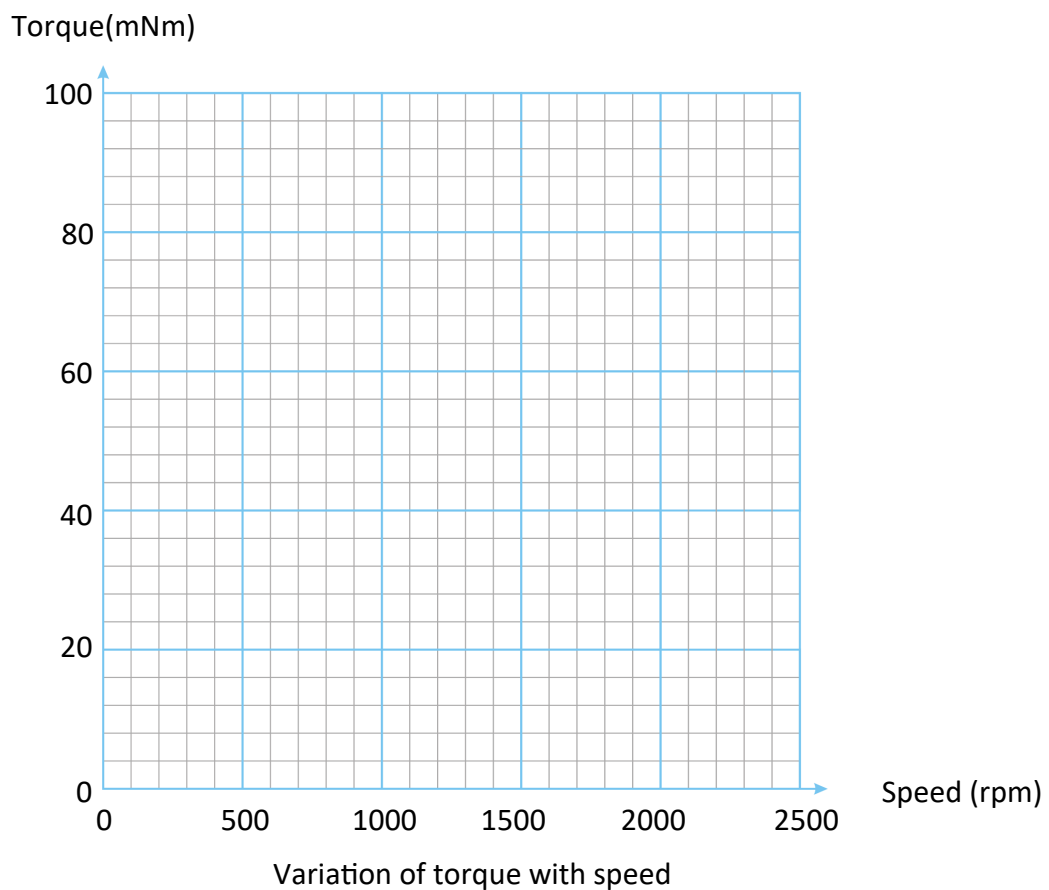
- 1) Set up the circuit shown above. Connect the DC motor to the control unit's DC1 power supply V+ and 0V terminals.
- 2) Energise the DC motor to put pressure on the dynamometer load cell rather than the balance. (If necessary, reverse the power supply connections.)
- 3) Connect the dynamometer to the load terminals on the control unit to set a load across the dynamometer.
- 4) Connect the control box to your computer using the USB lead.
- 5) On the computer, load the 'Open Control DC' program. Press the 'PLAY' style button on the top left and then click on the 'RUN' button.
- 6) Set the PWM DC output to around 30%.
- 7) Give the DC motor a small load of around 50% on the dynamometer.
- 8) Investigate the effect of varying the PWM voltage between 30% and 100%, taking six readings across that range. In the table on the next page record the speed, torque, and Driver Power coming from the power supply.
- 9) Use the information in the 'Key Relationships' section on page 4 to calculate the mechanical power delivered to the dynamometer.
- 10) In addition, calculate the efficiency of the motor at each of the six settings.
- 11) On the graph paper provided, use these readings to plot a graph to show how the torque (y-axis) varies with speed (x-axis).

Note that for repeated calculations you will find it easier to use a spreadsheet.

Worksheet 4

DC motor characteristics 1

Voltage	Speed	Torque	Electrical power	Mechanical power	Efficiency



So what?

Each motor has characteristics that make it suitable for particular applications in industry. In this learning package, you meet a variety of motor types and learn to appreciate their characteristics.

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Worksheet 5

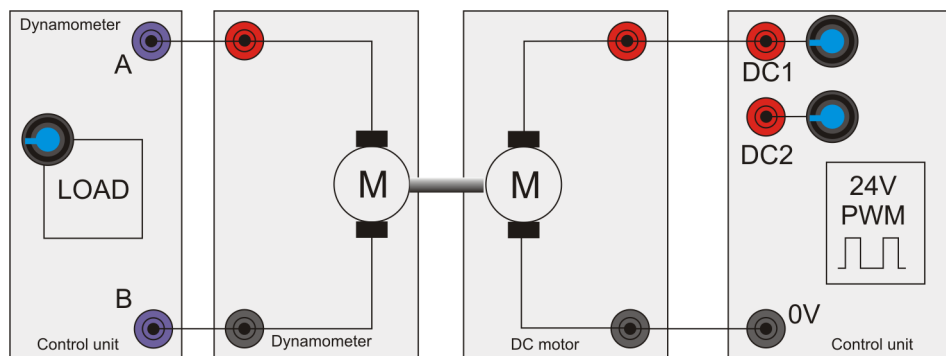
DC motor characteristics 2



Fairground 'dodgem' cars use simple DC electric motors operating at between 12 and 48V.

The vehicles have two brushes - one touching the metal floor, for 0V, and the other touching the metal ceiling, at a positive voltage.

Speed control is usually simple on-off.



Over to you:

- 1) Set up the circuit, connecting the DC motor to the control unit's DC1 power supply.
- 2) Connect the dynamometer to the load terminals on the control unit to set a load across the dynamometer.
- 3) Connect the control box to the computer using the USB lead.
- 4) On the computer, run the program 'Open LogDC.bat'.
- 5) Set the PWM DC output to around 50%.
- 6) Press the 'Sweep' button to run an automatic speed / torque log.
- 7) Repeat step 6 for DC outputs of 40%, 60%, 70%, 80% and 90%

- 8) The program logs the results into an Excel file. Its name is given in the 'Properties' section on the right of the screen. The program is stored in the 'Logs' subdirectory.

When the sequence is finished, load the results into Excel and use it to plot accurate speed torque graphs of the motor.

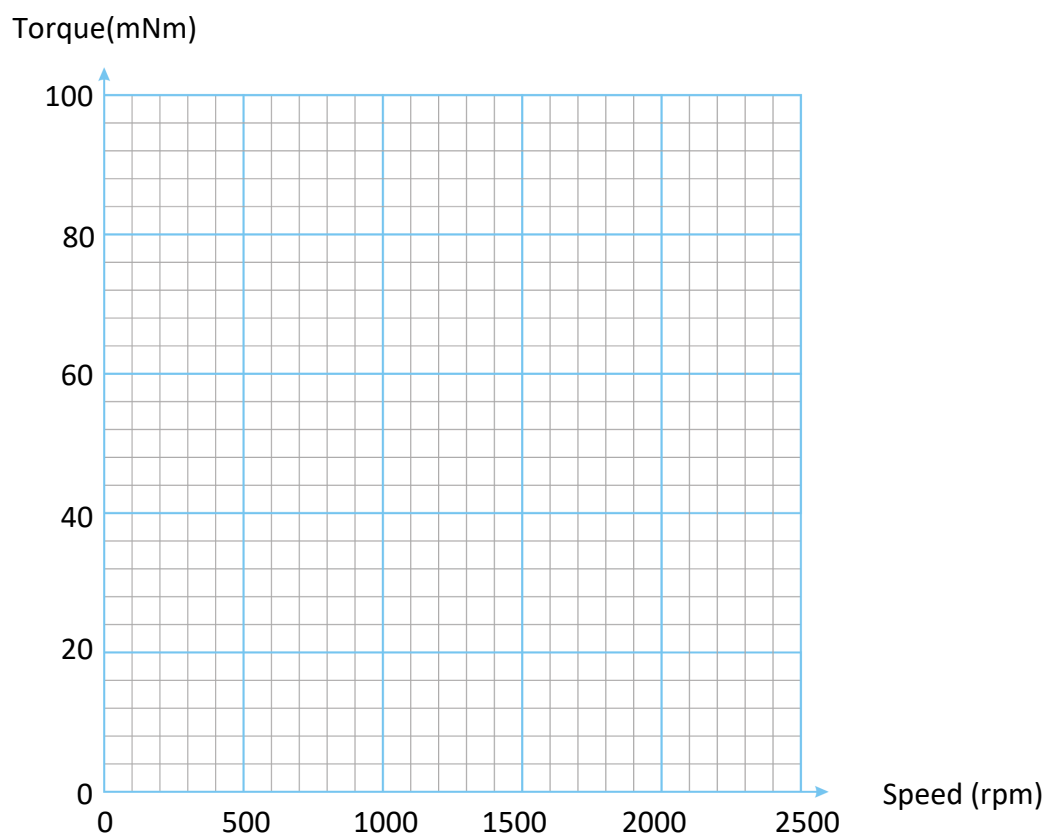
- 9) On the next page, sketch the results.

So what?

When looking at a motor's specification to check its suitability for a particular application, you often see a family of graphs showing its performance for different driving conditions. Understanding this information helps you to make the right choice.

Worksheet 5

DC motor characteristics 2



Effect of motor speed on torque for different values of
DC power supply voltages

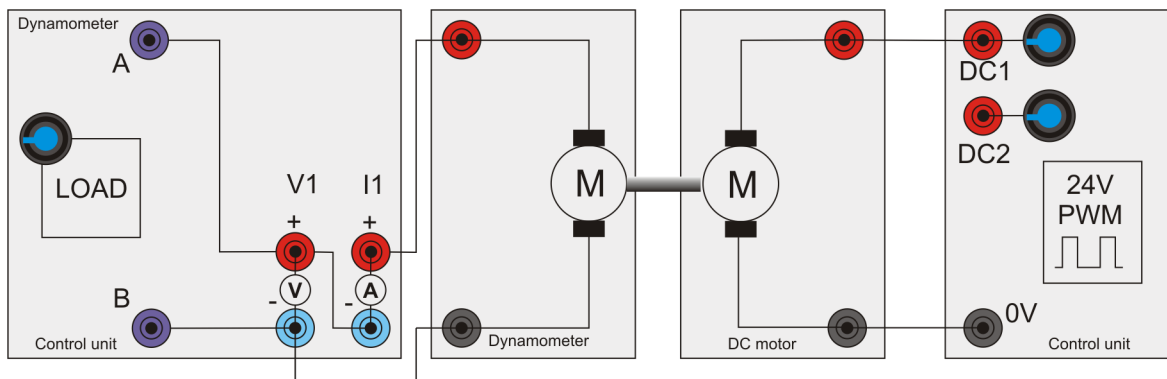
Worksheet 6

Permanent magnet generator (dynamo)



The electrical machine in the dynamometer has exactly the same characteristics as the DC motor. The only difference is physical - the drive shaft is longer.

The photograph shows a bicycle dynamo, used to power electric lights on the front and rear of the bike.



This worksheet examines the properties of a permanent magnet generator or 'dynamo', using the dynamo found in the dynamometer.

Over to you:

- 1) Set up the system shown in the diagram.
- 2) On your PC, run the program 'Open Control_DC.bat'.
- 3) Set the dynamometer load to 80%.
- 4) Use the program to take measurements of power out, speed, and torque generated by the dynamo for DC motor driving voltages of 40%, 50%, 60%, 70%, 80% and 90%
- 5) Use the formulae in the 'Key Relationships' section on page 4 to work out the mechanical power delivered into the dynamometer.
- 6) Calculate the efficiency of the conversion from mechanical to electrical power in the dynamometer.

- 7) Use the results to plot a graph, using the axes on the next page.

You may find it easier to use a spreadsheet to do the calculations.

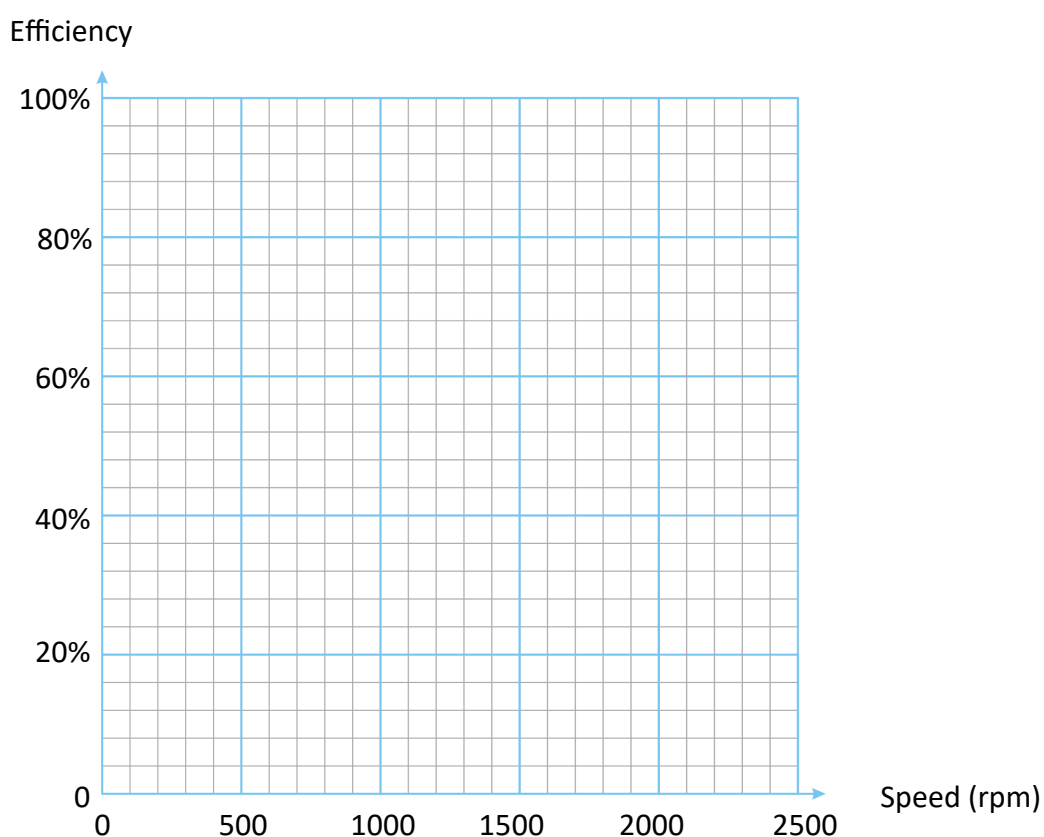
So what?

The efficiency of an electrical machine changes with its speed. Choosing the right combination of machine and gearbox for an application will help to get optimal efficiency.

Worksheet 6

Permanent magnet generator (Dynamo)

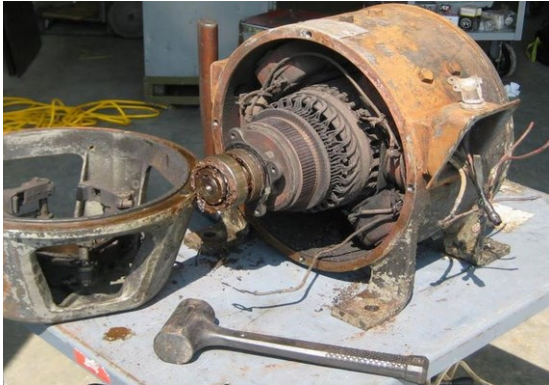
DC motor drive	Speed	Torque	Mechanical power	Dyno power	Dyno efficiency
40%					
50%					
60%					
70%					
80%					
90%					



Variation of efficiency with speed for a dynamo with a load of 80%.

Worksheet 7

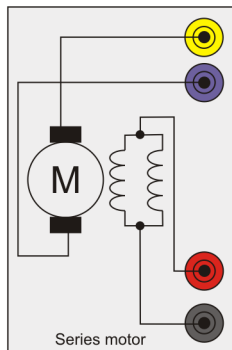
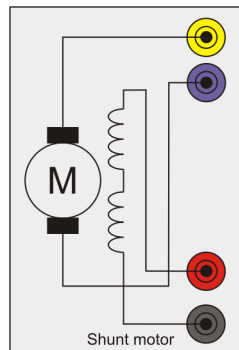
Shunt and series motor basics



Wound stator DC motors are often configured as either **shunt** wound or **series** wound.

The separate connections for the field windings of the stator and rotor / armature allow us to control the current in both parts of the motor separately, in order to examine the motor's behaviour.

The photograph shows an old shunt wound motor.



Red and black terminals are for the stator windings, yellow and purple terminals for the rotor windings.

Over to you:

- 1) With both the series and shunt motors disconnected from the test rig, use a digital multimeter to measure the resistance of the stator windings on both the shunt and series motors.
- 2) Use the Ohm's law formula, $I = V/R$, to calculate the theoretical field currents when the field windings are connected to a 24V DC supply.
- 3) Repeat the resistance measurement for the rotor windings
- 4) Record your results in the table opposite.
- 5) In practice, you get different values of current which we discuss below.

Stator windings

Motor	Resistance in Ω	Current in A
Shunt		
Series		

Rotor windings

Motor	Resistance in Ω	Current in A
Shunt		
Series		

Worksheet 7

Shunt and series motor basics

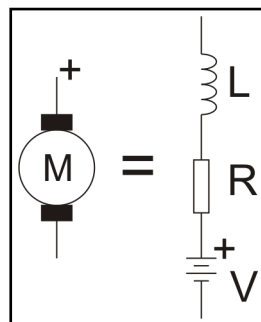
So what?

Electrical machines are made up of multiple windings. When DC flows through them, their electrical characteristics can be predicted using the Ohm's law formula. However, once the electrical machine is running the rotating magnetic fields in the machine alter their behaviour drastically.

The equivalent circuit of the machine then becomes more complicated. In particular, the rotating magnetic components in the machine induce an electromagnetic force (e.m.f.) which acts to oppose the flow of current in the windings. You can see the equivalent circuit below.

Understanding how to calculate this opposing e.m.f. is outside the scope of this learning package - but you need to be aware that it exists.

The reverse e.m.f. increases as speed increases. When a machine stalls, therefore, the reverse e.m.f. is reduced. The current flowing then increases significantly, increasing the risk of burning out the motor .



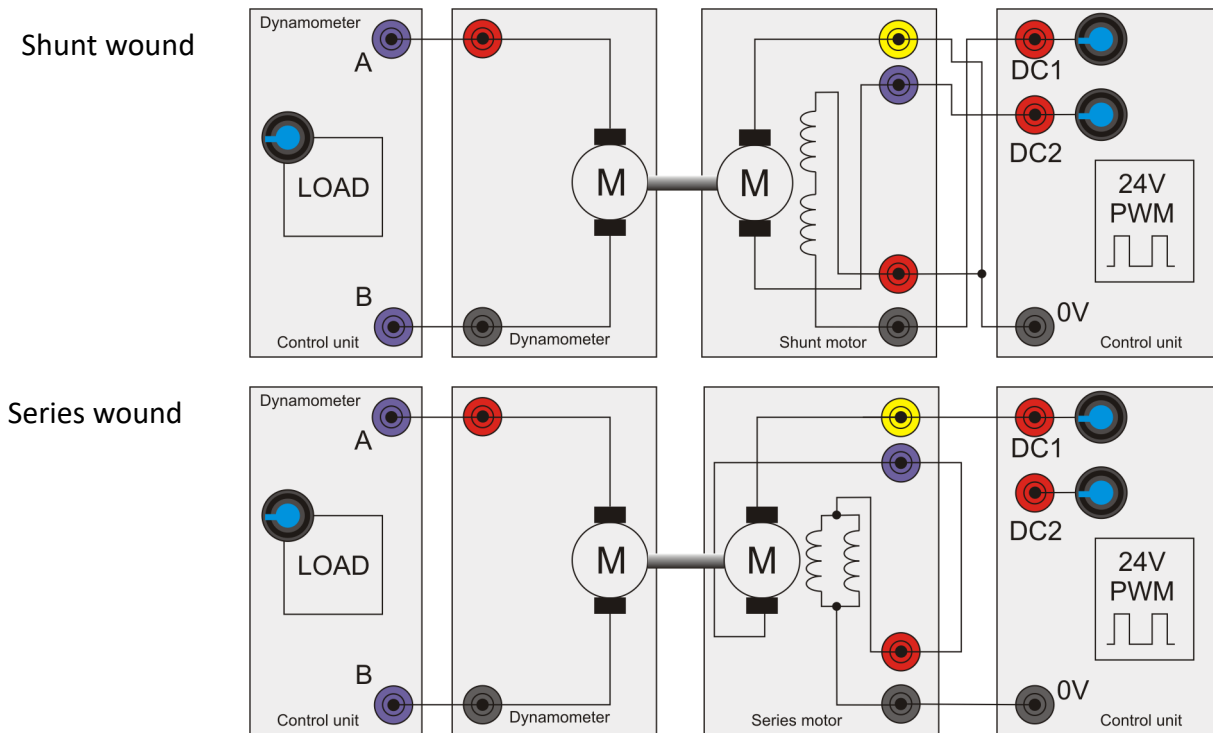
Equivalent circuit of a simple DC machine.

Over to you:

- 1) Connect the multimeter to the rotor winding of the Shunt motor on the ohmmeter setting.
- 2) Slowly turn the motor shaft. Explain what you see on the meter.

Worksheet 7

Shunt and series motor basics



Note: the circuits are similar but not quite the same.

With all wound-stator DC motors, you swap over the connections to **either** the stator **or** rotor windings to make the motor rotate in the opposite direction.

Reversing the voltage to both sets of windings keeps the motor rotating in the same direction, as both fields are reversed.

Over to you:

- 1) Set up the **shunt** motor as in the top diagram.
- 2) On your PC, load the 'Open Control_DC.bat' program. Set the output on DC1 (the field coils) to 100% or 24V. Set the output on DC2 (the rotor) to around 70% and press 'RUN'.
- 3) Increase DC2 in steps of 10% up to 100%. In the table on the next page, record the voltages and currents at each stage.
- 4) Now, change to the **series** motor and wire it up as in the lower diagram.
- 5) Set the output on DC1 to 40% and press RUN.
- 6) Increase DC1 in steps of 5%. Again, record the output voltages and currents each time. The currents eventually gets so high that the control unit cuts out.

So what?

This experiment shows that the speeds of the series and shunt motors are very different for similar voltage inputs .

The control unit cuts out at a certain speed (current) for the series motor. The current is limited to protect the motor and the control unit.

The control unit delivers an output power up to 100W. It cuts out when this is exceeded and shows an 'Err' message on the front of the unit. The software application stops.

Worksheet 7

Shunt and series motor basics

Shunt motor

DC1 %	DC2 %	I1 in A	I2 in A	Speed in RPM
100	70			
100	80			
100	90			
100	100			

Series motor

DC1 %	I1 in A	I2 in A	Speed in RPM
40			
45			
50			
55			

Indicate clearly the point at which the control unit cuts out.

So what?

The speed of the Series motor is very high. The Control unit is designed to cut out at speeds above 3100 RPM. Above this the Dynamometer produces voltages that can be dangerous.

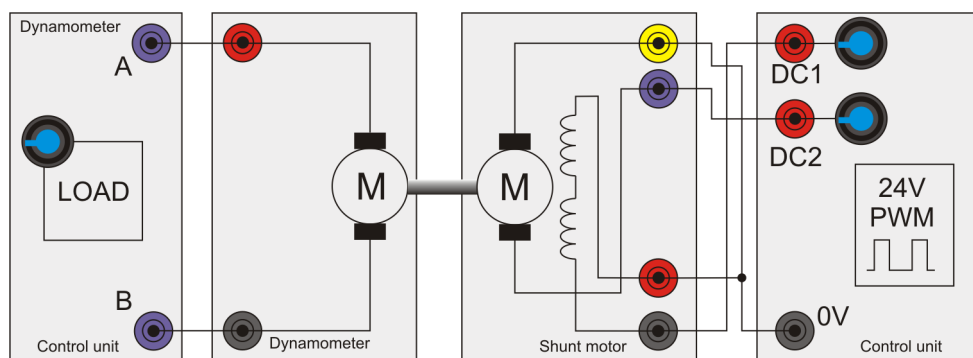
Worksheet 8

Shunt-wound motor characteristics



Speed control is an important element of electromechanical system design.

Some motors are better than others at self-regulating speed. The shunt motor is really good at speed regulation and for this reason they are often used in devices like lathes, which need to run at a constant speed.

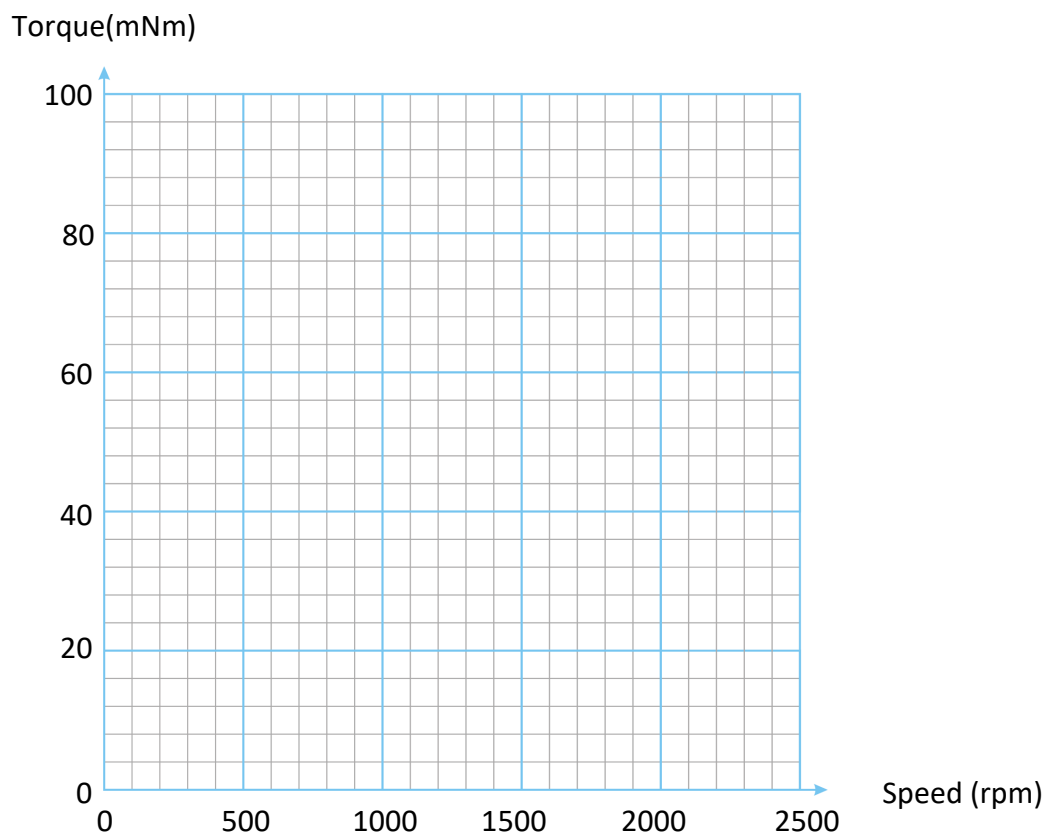


Over to you:

- 1) Set up the shunt motor as shown above.
- 2) On your PC, run the program 'Open Log_DC.bat'.
- 3) Open the program. Set the DC1 output to 100% to power the **stator winding** and the DC2 output to around 50% for the **rotor**.
- 4) Run the program and press 'Sweep' to take an automatic set of readings for a range of dynamometer loads.
- 5) Repeat steps 4 for **rotor** DC outputs of 60%, 70%, and 80%.
- 6) When the sequence has finished load the results into Excel and use Excel to plot a graph of speed and torque.
- 7) On the next page, use the axes provided to sketch the results.

Worksheet 8

Shunt wound motor characteristics



The effect of speed on torque for different values of stator coil volt-

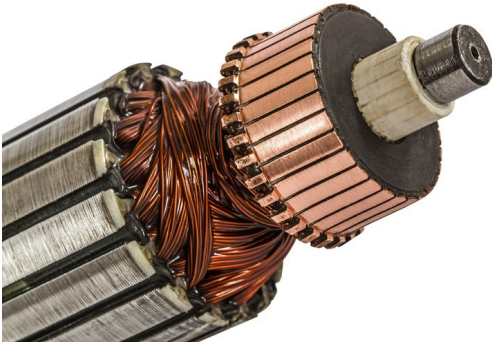
Over to you:

- 1) With the same equipment set up, load the program 'Open Control_DC.bat'
- 2) Route the Dynamometer output to the control unit Voltmeter. The software gives Dynamometer current. Now you can get Dynamometer voltage and current and calculate power in.
- 3) Run the program and set the DC output for the rotor to 50% and the output for the stator winding to around 50%.
- 4) Complete the table to show speed, output power, dynamometer power and efficiency.

Stator Voltage DC1 (V)	Rotor Voltage DC2 (V)	Input power (W)	Speed (rpm)	Angular speed (rads/s)	Torque (Nm)	Output power (W)	Efficiency (%)
50%	50%						
70%	70%						

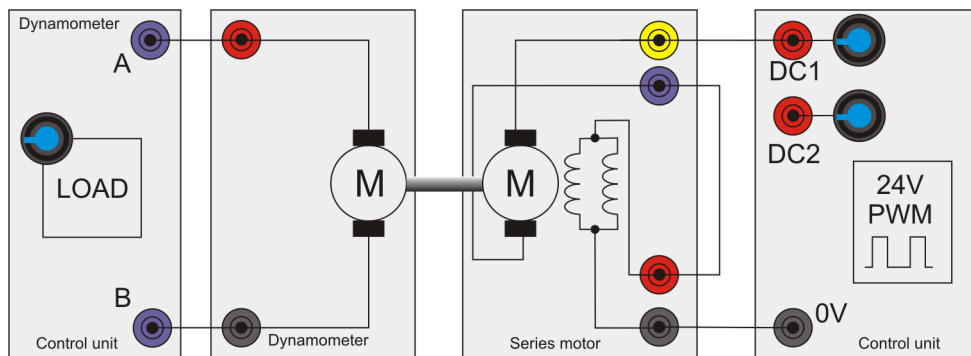
Worksheet 9

Series-wound motor characteristics



A series-wound motor has the highest torque on start-up of any motor. However, its speed varies as the load varies. It is ideally suited to applications such as winches and cranes where the initially high torque is important.

The photograph shows a typical wound rotor with split ring commutator.

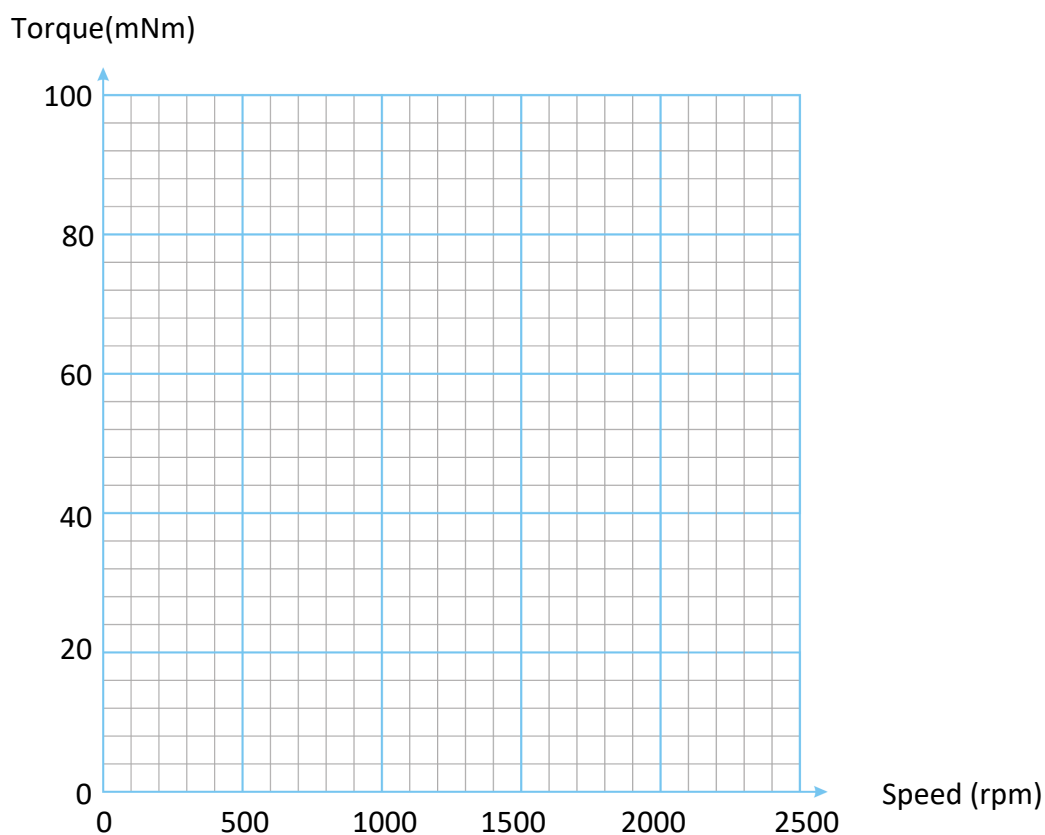


Over to you:

- 1) Set up the series motor as shown above.
- 2) On your PC, run the program 'Open Log_DC.bat'.
- 3) Run the program with the DC output set to around 35%.
- 4) Make sure the motor is putting pressure on the load cell rather than the balance - just reverse the direction of rotation if it is not.
- 5) Press 'Sweep' to take an automatic set of readings for a range of dynamometer loads.
- 6) Repeat steps 3, 4 and 5 for DC outputs of 40%, 45%, and 50%.
- 7) When the sequence has finished load the results into Excel and use Excel to plot a graph of speed vs torque.
- 8) On the next page sketch graphs to show traces for all output voltages.

Worksheet 9

Series wound motor characteristics



The effect of speed on torque for different values of DC output voltage.

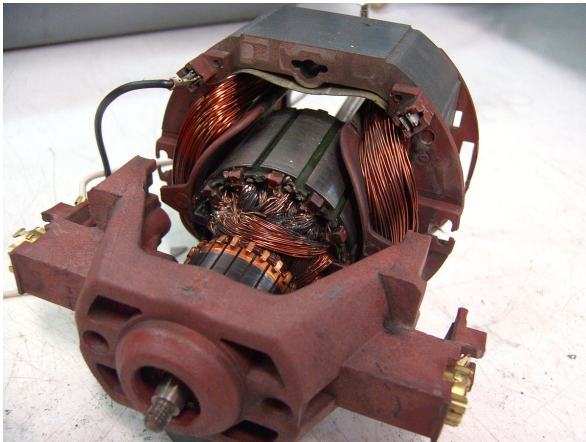
Over to you:

- 1) With the same equipment set up, load the program 'Open Control_DC.bat'.
- 2) Route the Dynamometer output to the control unit Voltmeter. The software gives Dynamometer current. Now you can get Dynamometer voltage and current and calculate power in.
- 3) Run the program and set the DC1 output to around 30%
- 4) Complete the table to show speed, output power, dynamometer power and efficiency.

Supply Voltage DC1 (V)	Input power (W)	Speed (rpm)	Angular speed (rads/s)	Torque (Nm)	Output power (W)	Efficiency (%)
30%						
60%						

Worksheet 10

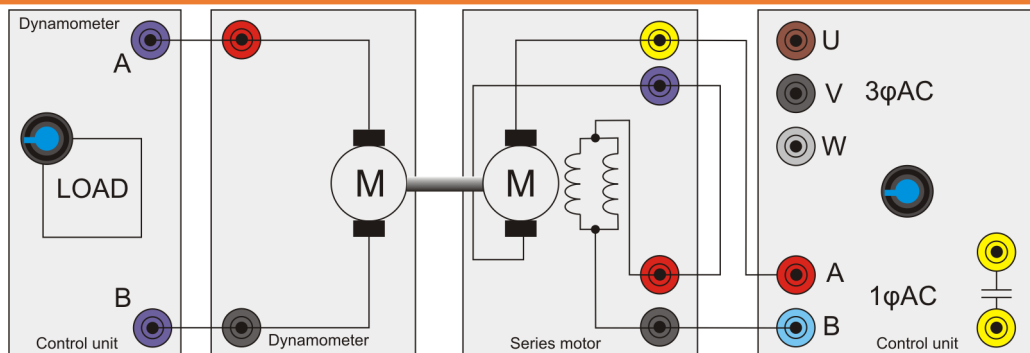
Universal motor



The series-wound motor is often called the 'universal motor' because it can be operated from AC as well as DC.

This flexibility means that universal motors are amongst the most widely used.

Typical applications include planes, routers, sanders, grinders, saws etc.



This worksheet examines the AC behaviour of the series-wound motor.

Over to you:

- 1) Set up the series motor as shown above.
- 2) On your PC, load 'Open Log_1Phase.bat' and press 'Play'.
- 3) Set the Driver voltage to around 20V.
- 4) With the output frequency set at 50Hz, run the program and use the 'Sweep' function to take an automatic set of readings over a range of dynamometer loads.
- 5) When the sequence has finished, use Excel to plot a graph of speed vs torque.
- 6) Repeat this procedure for frequencies of 60, 70, and 80Hz.
- 7) On the next page sketch graphs to show traces for all frequencies. Compare AC and DC

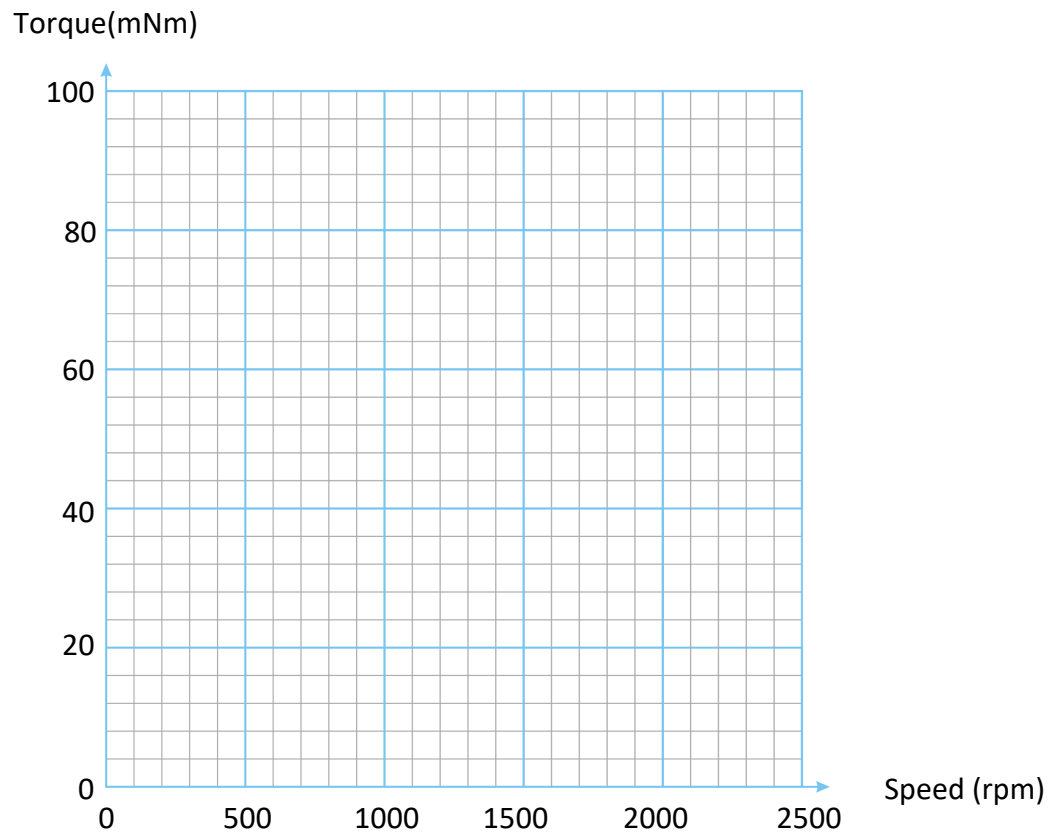
properties of the universal motor.

How do you change direction of motion?

Set the frequency to 40Hz - what happens?

Worksheet 10

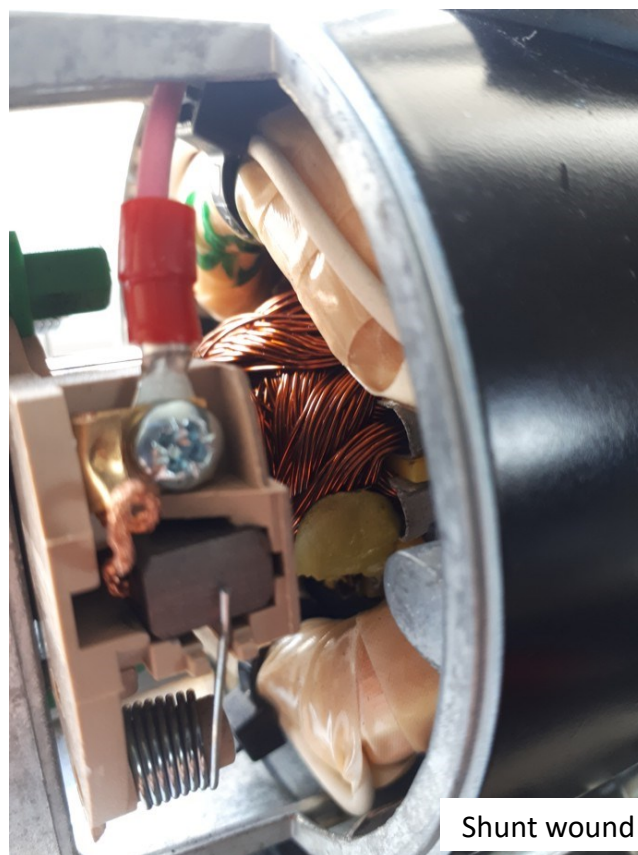
Universal motor



The effect of speed on torque for different values of output frequency.

Worksheet 11

Comparing shunt and series motors



Over to you

1) Comparing the photographs, what is the difference between the rotor windings?

¹⁾
2) Earlier you measured the resistance of the shunt and series motor windings.
Do these photographs corroborate your findings?

3) Research the term 'separately excited'. What does this mean?

Worksheet 12

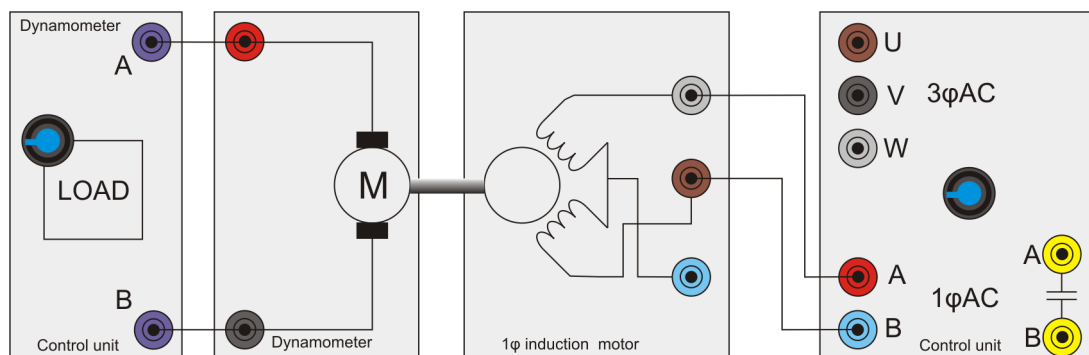
Single-phase induction motor



One problem with series and shunt motors is that they use 'brushes' in the rotor circuit. These wear out and need replacing from time to time.

Induction motors have no brushes and so require less maintenance.

The photograph shows an induction motor and its fitted gearbox.



Over to you:

- 1) Set up the single phase induction motor as shown in the diagram above.
- 2) On your PC run 'Open Control_1Phase.bat'
- 3) Connect the windings to terminals **A** and **B**. When the software application is running, these give a single phase output signal.
- 4) However, you will find that the motor does not start.

Oh dear!

So what?

You have just discovered a problem with the induction motor - it needs something to get it started.

When the induction motor is powered, a little physical nudge in one direction often starts it. Unfortunately, in this rig, you cannot touch the shaft, for safety reasons.

Another problem is that it does not matter which direction you nudge the motor in - it can rotate either way.

Next we will look at how to make the system more predictable.

Worksheet 13

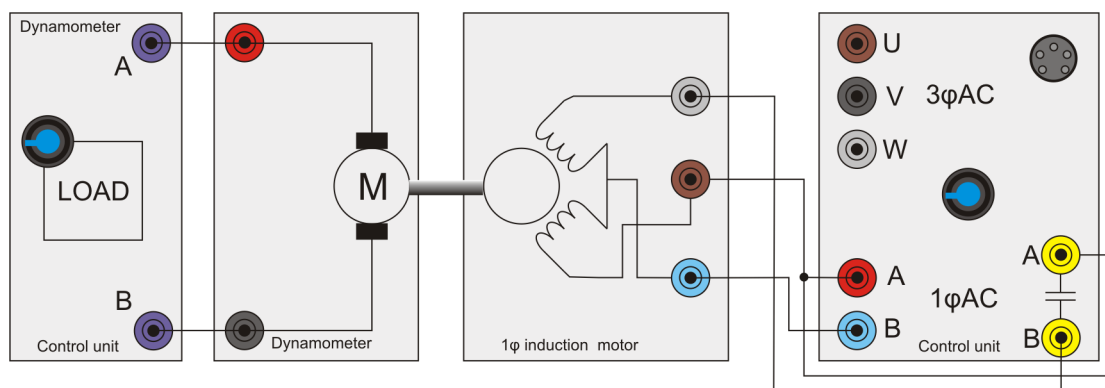
Single phase induction motor - cap start



In many situations, engineers have a choice over which type of motors to use.

For simple AC applications, like pressure washers, they can use either an induction motor or a series motor.

The choice is governed by the electromechanical properties of the motor - the cost, size and long-term reliability required.



Over to you:

- 1) Set up the single phase induction motor as shown in the diagram above.
 - 2) On your PC load 'Open Log_1phase.bat' and press 'Play'.
 - 3) Use settings Voltage: 20V, CAP start, SINE.
 - 4) Once the motor is running select CAP Run.
 - 5) With the output frequency set at 50Hz, run the program and use the 'Sweep' function to take an automatic set of readings over a range of dynamometer loads.
 - 6) When the sequence has finished, use Excel to plot a graph of speed vs torque.
- Repeat this procedure for frequencies of 60, 70, 80, 90 and 100Hz.
- 8) On the next page, sketch graphs to show trac-

es for all frequencies.

So what?

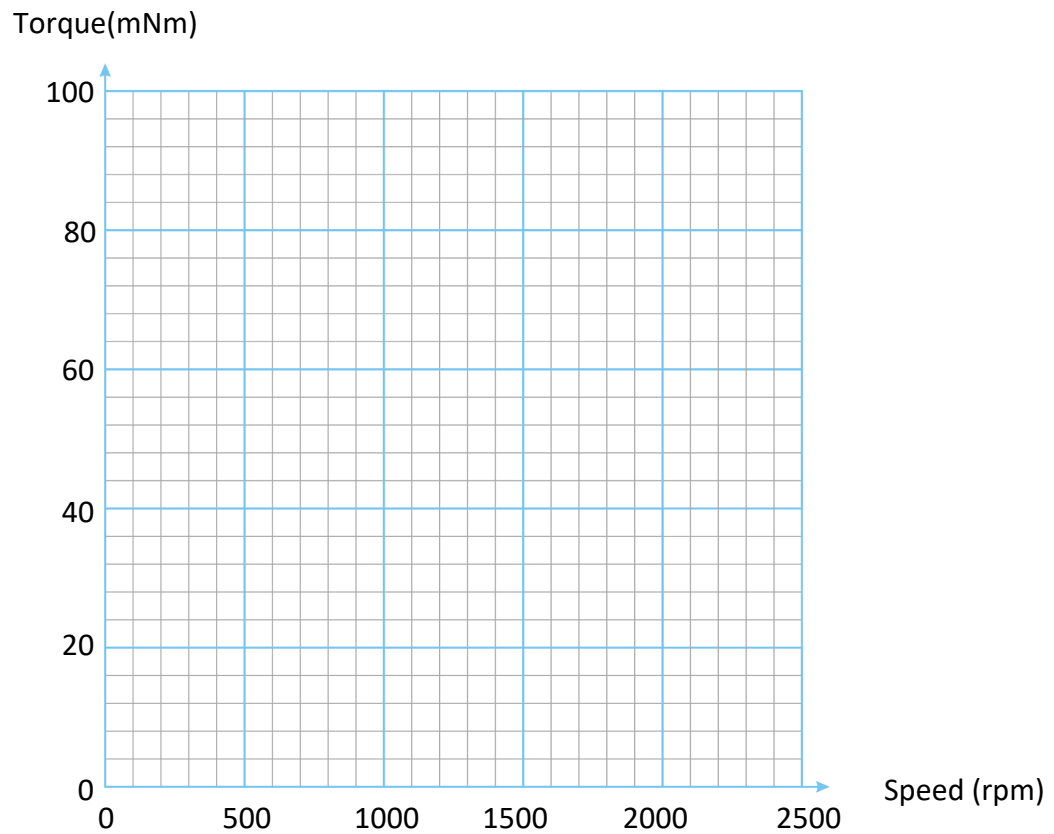
How do you change direction of rotation?

How do the speed / torque curves compare to the other motors you have looked at?

What are the advantages and disadvantages of DC and AC machines?

Worksheet 13

Single phase induction motor - cap
start



The effect of speed on torque for different values of output frequency.

Worksheet 14

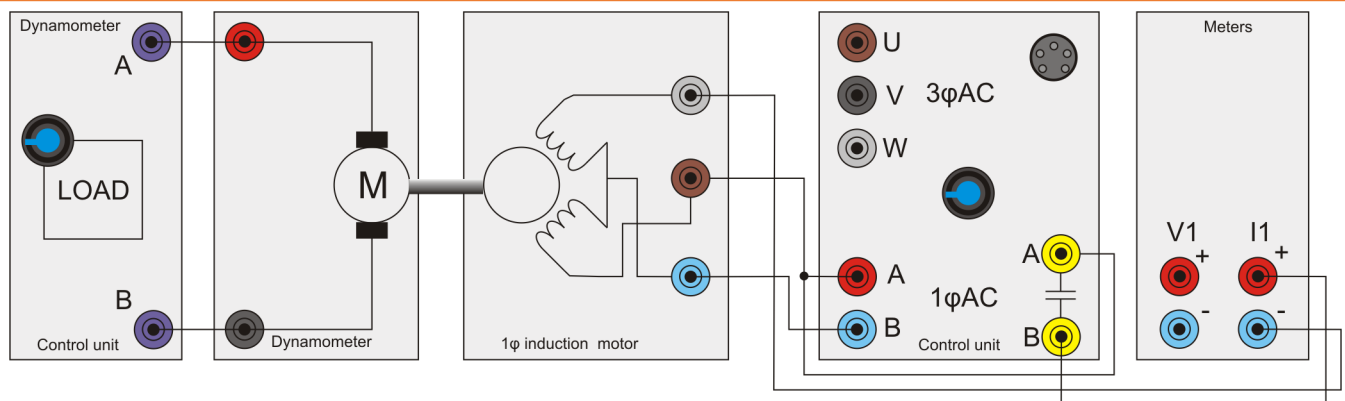
Phase shift in induction motors



One of the drawbacks of the single-phase induction motor is that it needs an external capacitor to make it operate.

The induction motor is very reliable because it has no brushes. However the capacitor used to start the motor must be switched out of the circuit once the motor is running.

This needs either additional electronic switching circuitry or a centrifugal mechanical switch.



Over to you:

- 1) Set up the single-phase induction motor as shown in the diagram. This experiment uses the oscilloscope built into the control unit to look at the phase shifts in the windings caused by the Start/Run capacitors.
- 2) On your PC run 'Open Control_1Phase.bat'.
- 3) Use settings Voltage: 20V, CAP start, SINE.
- 4) Set the frequency to 50Hz.
- 5) Set the 'scope to show I and IA, using the 'Properties' on the right hand side of the screen. Capture the waveform.
- 6) Sketch what you see on oscilloscope grid on the next page .
- 7) Repeat the procedure for frequencies of 60Hz, and 70Hz. For each frequency, record the currents and phase shift.
- 8) Investigate the effect of changing from the 'Start' to the 'Run' capacitor, using the 'Capacitor Start / Run' selector switch.

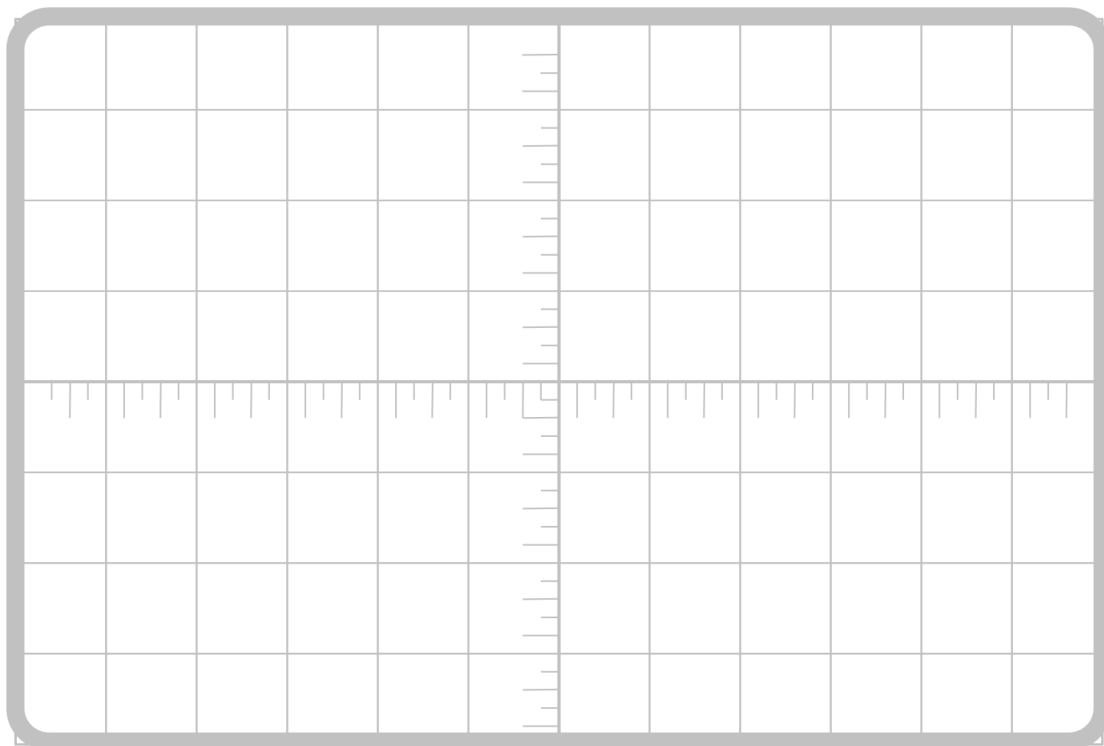
So what?

Without a capacitor, the motor would not start. In some systems - like this one - the motor has two capacitors, one value for starting and one for running. The phase shift for each is different. For the same voltage, how much more efficient is the 'Run' capacitor than the 'Start' capacitor for each frequency?

Investigate why a different value is needed for 'Start' and 'Run'.

Worksheet 14

Phase shift in induction motors



AC drive frequency (Hz)	Output power (W)	Output voltage (V)	Output current A (A)	Phase (deg)	Resolved power (W)	Efficiency (%)
50Hz						
60Hz						
70Hz						

Note that you can change the current settings in the software properties box on the right of the screen.

The Resolved power can be determined through trigonometry using $V \times I \times \cos(\text{Phase})$.

Worksheet 15

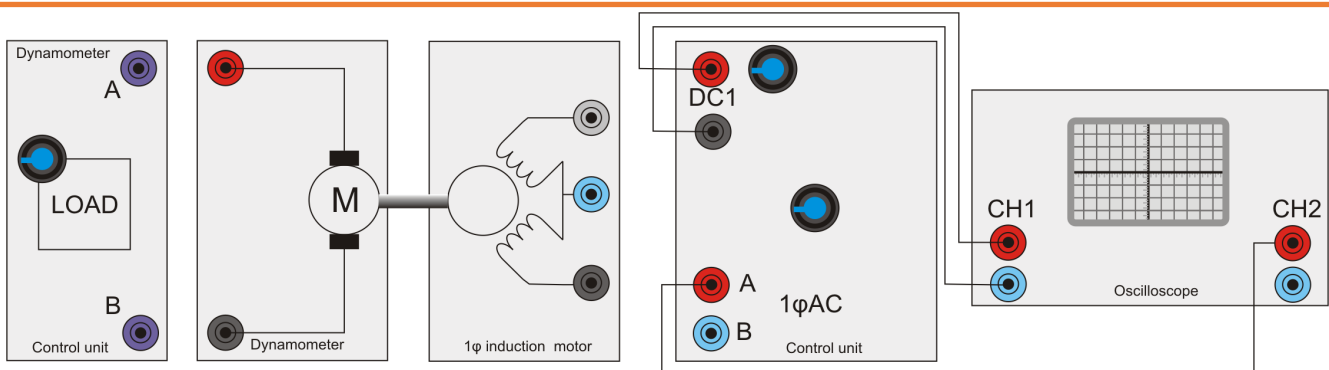
Variable frequency drive strategies



In factories, induction motors are often used at fixed speeds, dictated by the 50 or 60Hz mains supply.

Where speed control is needed it requires a change in strategy.

This photograph shows variable frequency drives used in a mineral water plant.



**Do not use a PC-based oscilloscope.
Use a traditional 'scope with no USB connection to the PC.**

Over to you:

- 1) Set up the single-phase induction motor as shown in the diagram above.
In this exercise, we are just looking at signals and so the motor and dynamometer do not need to be connected. However, the motor must be in the dynamometer cradle in order to activate the power supply .
- 2) On your PC run 'Open Control_1Phase.bat'.
- 4) Select an output voltage of 24V and a frequency of 50Hz.
- 3) Connect the oscilloscope as shown. In this application, the DC1 output gives a pulse at the start of each cycle. This can be used to trigger the scope on channel 1 whilst looking at the waveform from output A on channel 2.

- 4) On the next page, sketch the waveform of the single-phase AC output A.

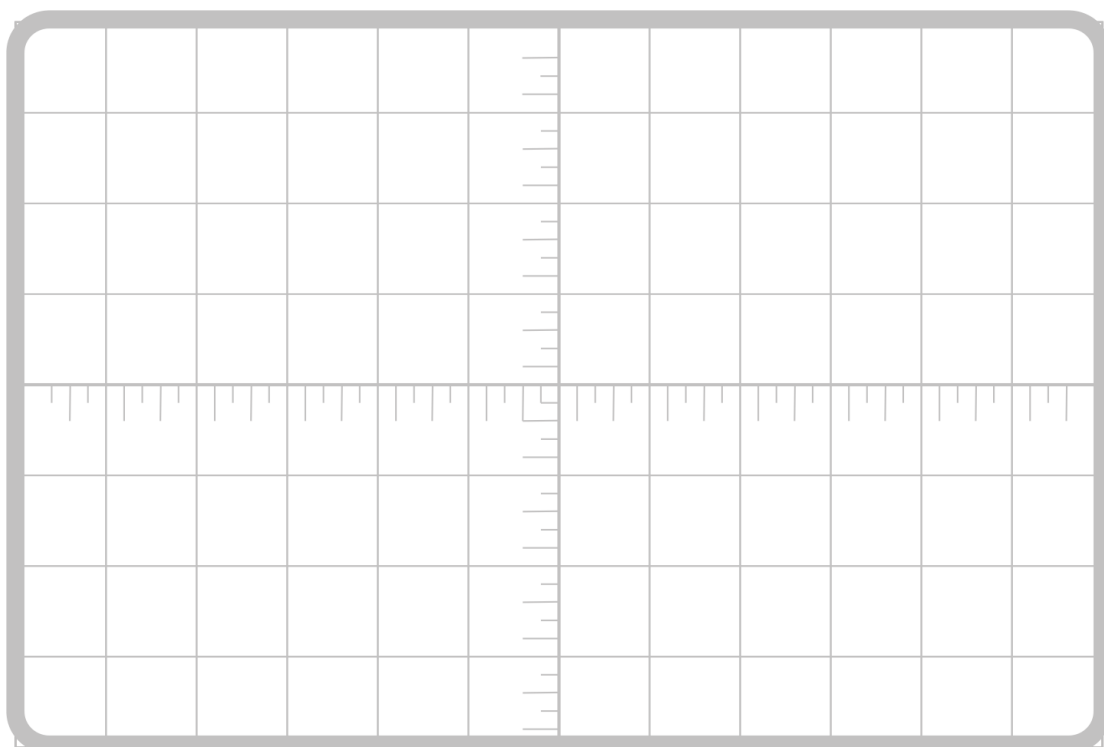
So what?

This exercise illustrates how PWM (Pulse Width Modulation) is used to create a waveform with variable pulse width but constant period, the period of the fundamental waveform.

When connected the motor drive coils act as a low-pass filter for AC signals, smoothing out the waveform. If you plotted the current through the windings it would be much more like a traditional sine wave.

Worksheet 15

Variable frequency drive strategies



Over to you:

- 1) Alter the output from SINE to DIGITAL. Sketch the output waveform on the same graph above.
- 2) With the oscilloscope connections unchanged add the single phase AC induction motor and start/run capacitor . Refer to the connection diagram in the Worksheet on Single phase induction motor if you need to.
- 3) With the dynamometer load at around 50%, measure and record in the table below the speed, torque, output power and input power, for frequencies of 50, 60 and 70Hz.

Digital drive characteristics

AC drive frequency	Speed in rpm	Torque	Output power	Input power
50Hz				
60Hz				
70Hz				

Worksheet 15

Variable frequency drive strategies

Over to you:

- 1) In the software application, click on the button marked 'Sine'. This reverts the output of the drive back to a pseudo-sine wave.
- 2) Sketch the output at **A** when using the trigger pulse on DC1. (You could compare the signal from **B**.)
- 3) Then, with the dynamometer load at around 50%, measure and record in the table below the speed, torque, output power and input power, for frequencies of 50, 60 and 70Hz.

Pseudo sine drive characteristics

AC drive frequency	Speed in rpm	Torque	Output power	Input power
50Hz				
60Hz				
70Hz				

So what?

It is surprising how well a simple digital drive signal works for the induction motor. However, when energy conservation is paramount, the cost of a few bits of silicon needed to create the drive circuit is of secondary importance.

Worksheet 15

Variable frequency drive strategies

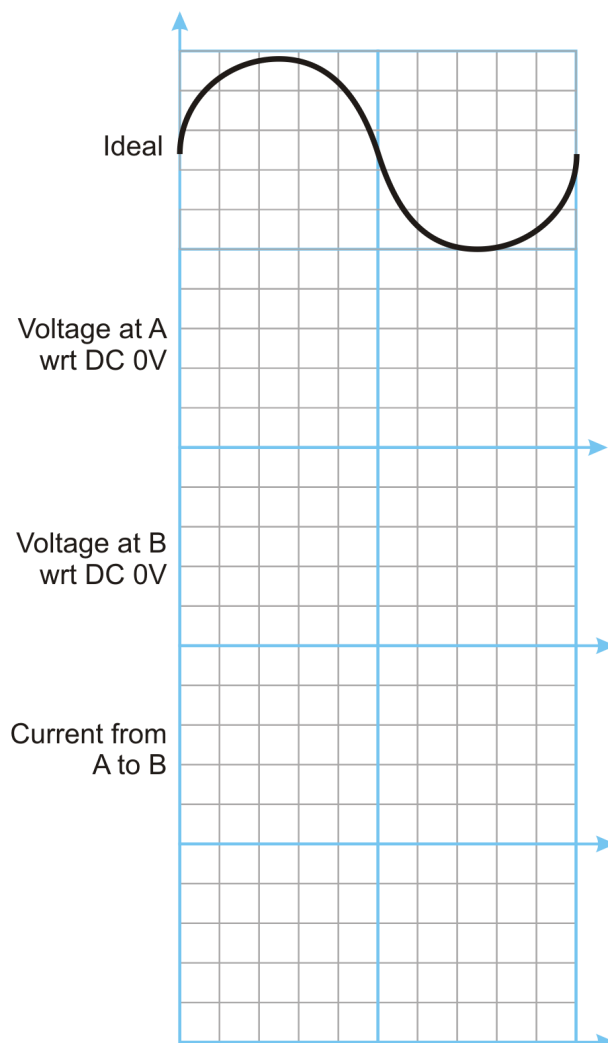
Over to you:

- 1) In the block diagram of the control unit in the 'Reference' section, the motor drive outputs are shown as 'tri state'. This means that each output voltage can be high, low or open circuit.

The single phase 24V maximum outputs **A** and **B** are alternately positive and negative, effectively creating a maximum peak-to-peak voltage of 48V across the motor.

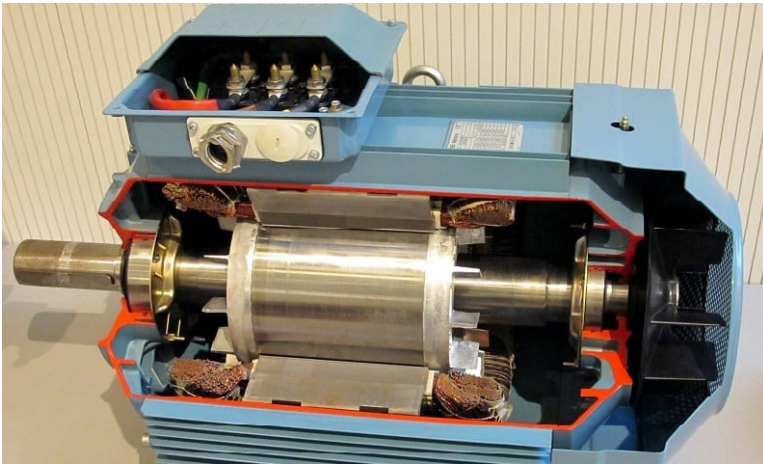
- 2) Obtain the waveforms and sketch them on the axes below.

You can use the on board oscilloscope here to look at the current waveform.
However the on-board scope is not fast enough to show PWM accurately.



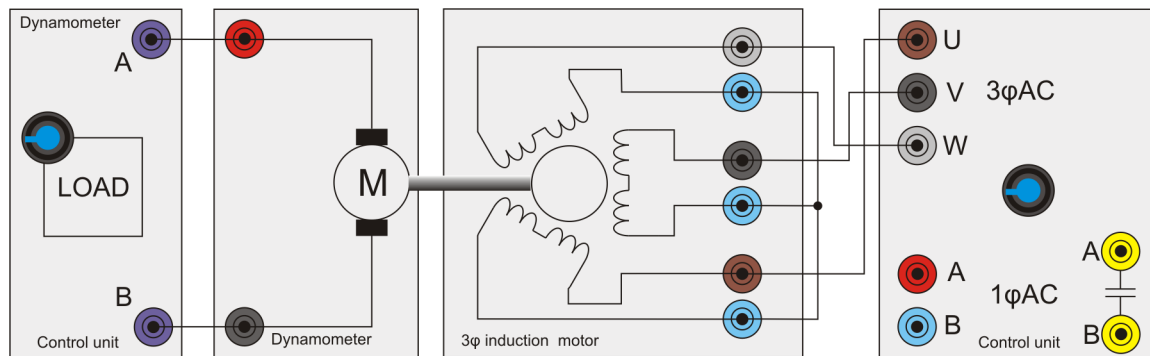
Worksheet 16

Three-phase motor characteristics



This photograph shows a section of a three phase motor with the outer shell cut away. Note the lack of brushes and the lack of a winding in the rotor.

Induction motors work by inducing a current, and magnetic field, into the rotor which has a slightly different phase to the driving current/field.

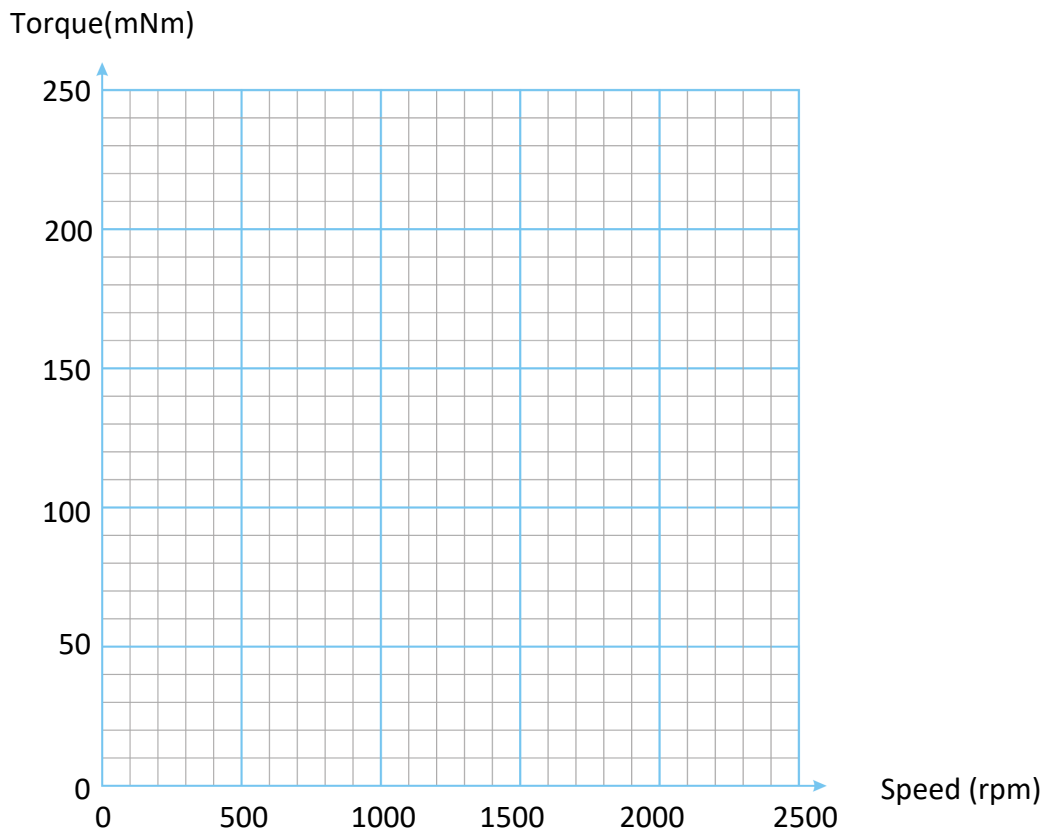


Over to you:

- 1) Set up the three phase induction motor as shown in the diagram above.
- 2) On your PC, load 'Open Log_3phase.bat'.
- 3) Use settings SINE, 20V, IMPROVED.
- 4) With an output frequency of 50Hz, run the program and take an automatic set of readings over a range of dynamometer loads.
- 5) Repeat this for output frequencies of 60, 70, 80, 90, 100 Hz.
- 6) If you can plot all output lines on the same graph.
- 7) On the next page, sketch the results .

How do you change direction of rotation?

Three phase motor characteristics



The effect of speed on torque for different values of output frequency.

So what?

Compare the speed/torque curves to those of the single-phase motor.

How does it compare for efficiency? Research the reason for this and give your findings below.

[illegible]

Worksheet 17

Three-phase motor drive strategies

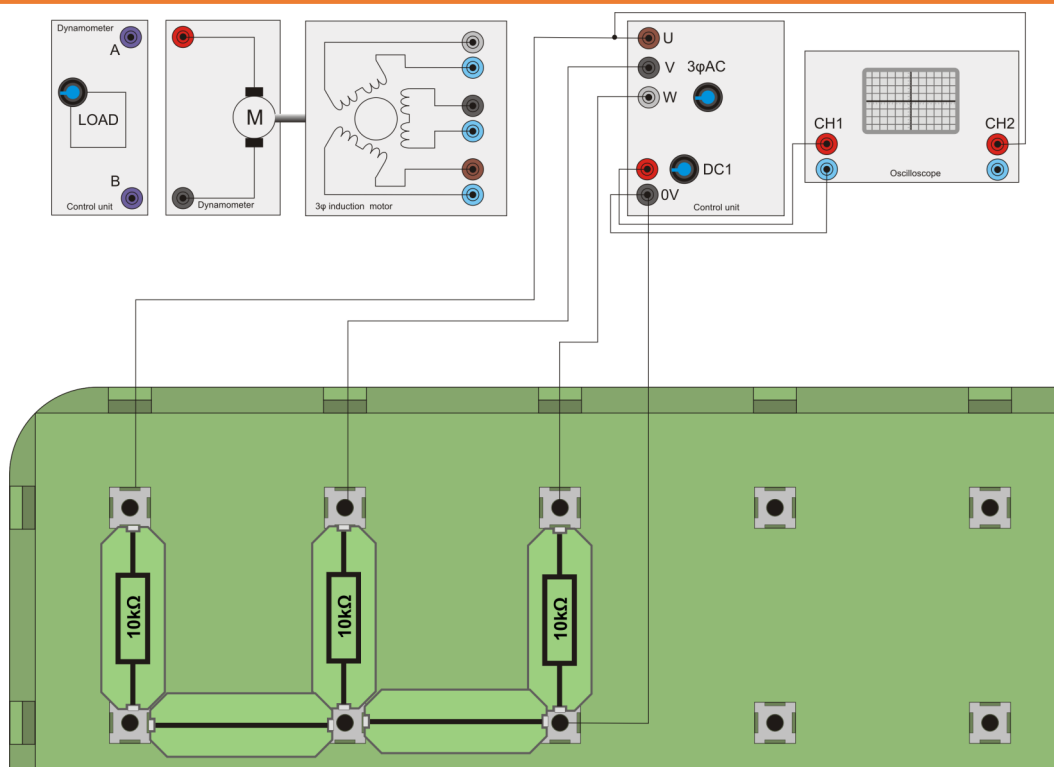


The National Grid distributes electricity in three separate phases rather than the single-phase found in homes. Three-phase generation is more energy efficient.

Factories use three-phase motors as they too are more efficient than single-phase systems.

The photograph shows a three-phase induction motor factory in China.

The photograph shows a three-phase induction motor factory in China.

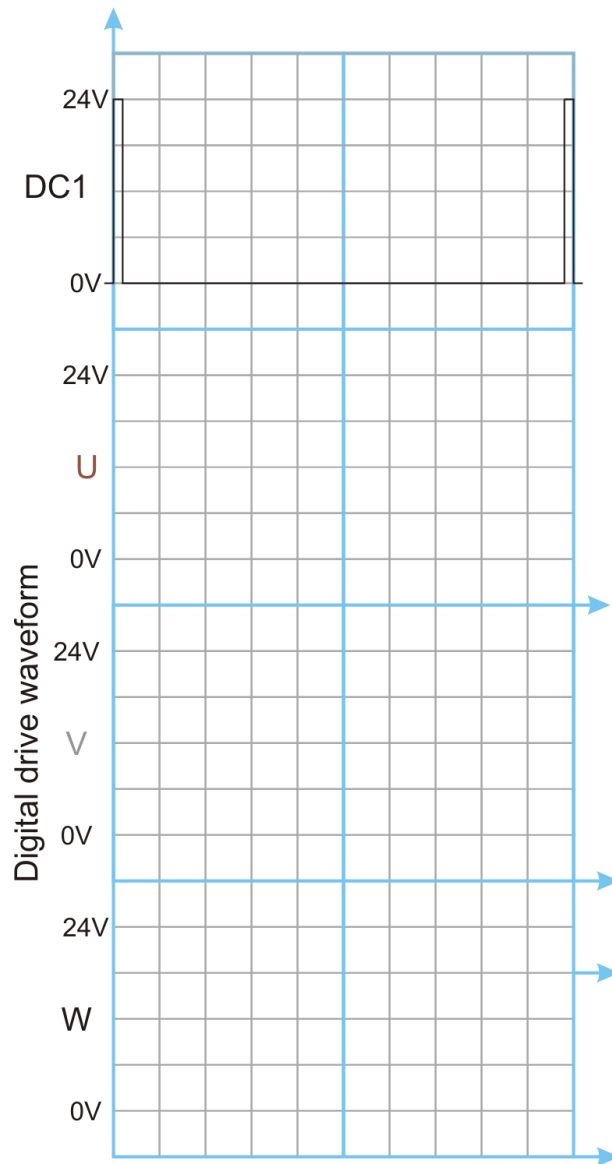


Over to you:

- 1) Set up the three-phase induction motor as shown in the diagram above. As this exercise looks only at the signals the generator unit creates, there is no need to connect the three-phase motor to the supply.
- 2) Connect three 10kΩ resistors as loads between U, V, W and 0V.
- 3) On your PC run 'Open Control_3Phase.bat'.
- 4) Press 'Play' and put the software into digital mode by pressing the 'Sine' button. This changes the waveform from pseudo-sine, constructed with PWM to a simple digital waveform where U, V, and W are 120 degree shifted square waves. Set the output frequency to 50Hz and press 'Run'.
- 5) Trigger an oscilloscope on the DC1 output. On the second channel display the output U.
- 6) Sketch the waveforms of signals U, V, and W, relative to the timing waveform on DC1.

Worksheet 17

Three phase motor drive strategies



So what?

Notice that these pulses are 120° apart. Together, they make up the basic three-phase waveform.

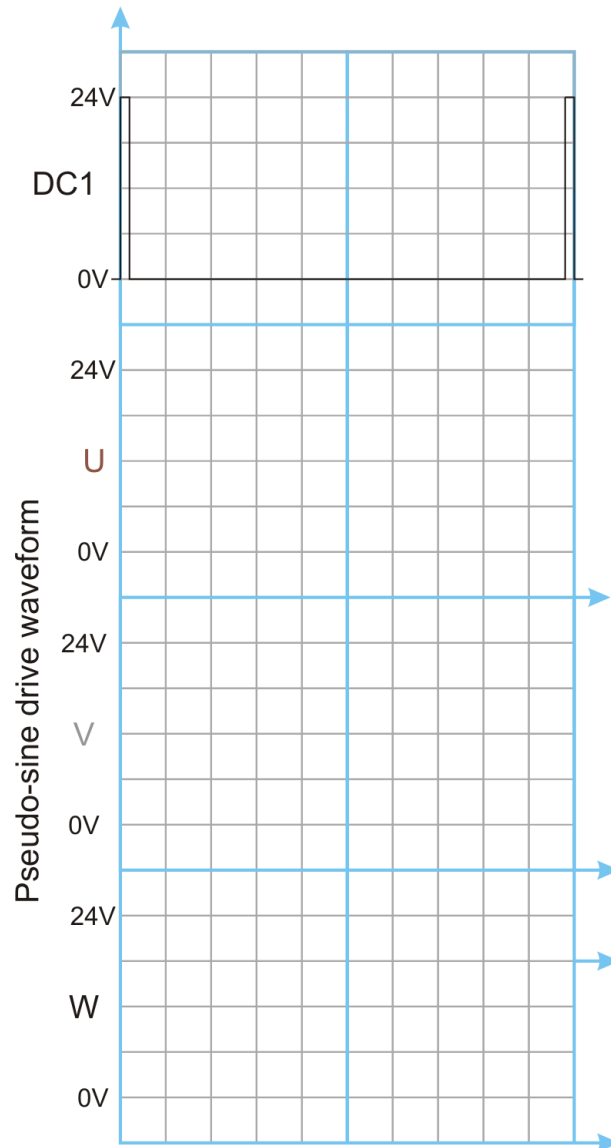
You should notice that each waveform spends some time at 0V, some time at 24V and some time when it is in between, at around a volt or so. What you are seeing is the three stages of drive of each output - forced to 0V, forced to +24V and left open circuit. In this last stage, the voltage is not dictated by the power supply but by the rest of the circuit.

Worksheet 17

Three phase motor drive strategies

Over to you:

- 1) Still with the $10k\Omega$ resistive loads in place, change the drive waveform to pseudo sine at 50Hz.
- 4) Once again, sketch the waveforms of signals U, V, and W , relative to the timing waveform on DC1.



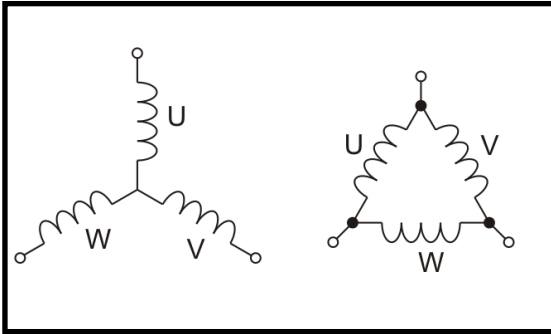
So what?

You now see the waveforms that make up the three-phase drive. There are in fact six separate steps to this. Hence it is often called the 'six step three-phase motor drive system'.

Some three-phase speed control systems use simple square waves for driving motors. However the pseudo-sine wave you have examined is much more efficient.

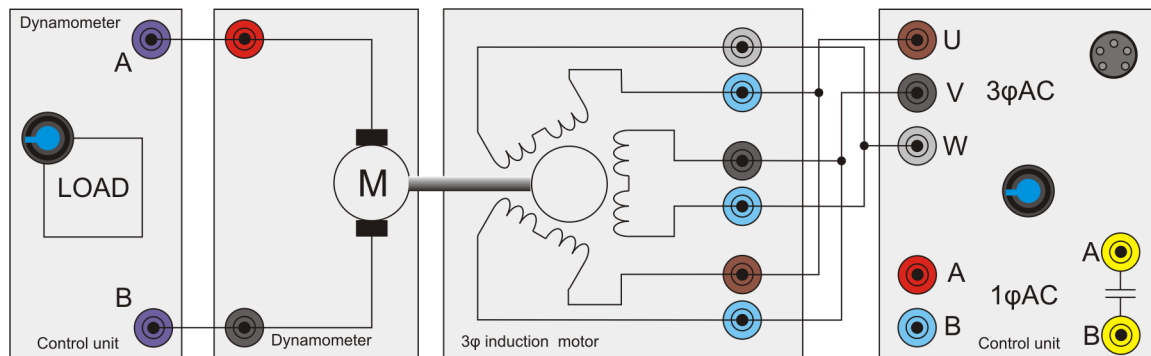
Worksheet 18

Delta configuration



Induction motors can be used in 'star' or 'delta' configuration. This terminology just refers to the way the windings are connected to the supply. Delta connection tends to be used when higher current or higher power is needed.

Image shows the wiring connections of star and delta.



Over to you:

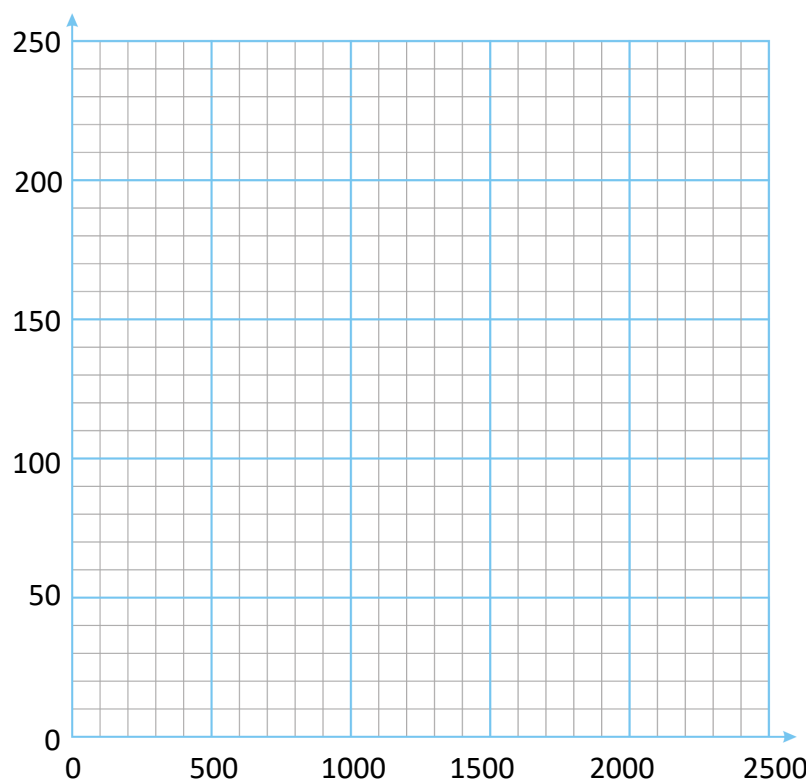
How do you change direction of rotation?

- 1) Set up the three phase induction motor as shown in the diagram above.
- 2) On your PC, load 'Open Log_3phase.bat'.
- 3) Reduce the output voltage to 12V using the slider. In Delta configuration the resistance of the windings to the power supply is much lower and the control box will trip if you draw too much current.
- 4) With an output frequency of 50Hz, run the program and take an automatic set of readings over a range of dynamometer loads.
- 4) Repeat this for output frequencies of 60, 70, 80, 90, 100 Hz.
- 5) If you can plot all output lines on the same graph.
- 6) On the next page, sketch the results .

Worksheet 18

Delta configuration

Torque(mNm)



Speed (rpm)

The effect of speed on torque for different values of output frequency.

So what?

What can you say about the power consumed and the torque of both star and delta configurations.

Worksheet 19

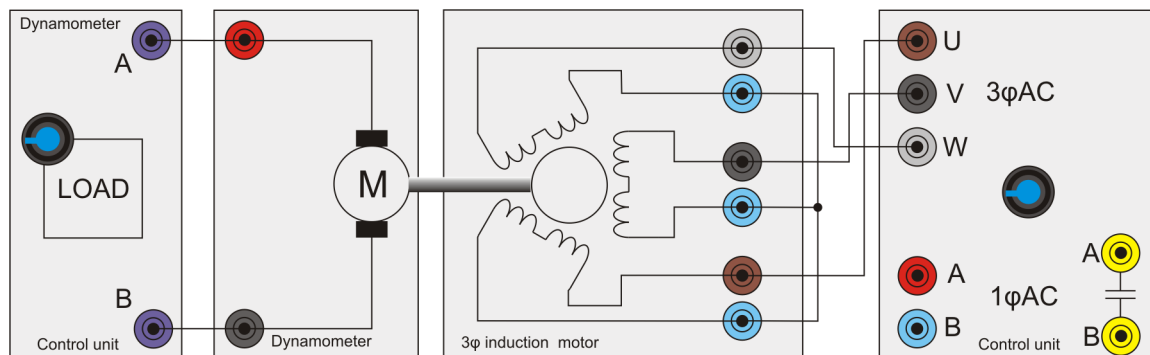
Understanding slip



Whilst induction motors may vary in size, their characteristics are all similar.

Larger motors can be very expensive. When they fail, they are refurbished by hand - a specialist task.

In the photograph, an engineer is re-winding an induction motor.



Over to you:

- 1) Set up the three-phase induction motor as shown in the diagram above.
- 2) On your PC run 'Open Control_3Phase.bat'.
- 3) Calculate the synchronous speed for the three-phase motor using the formula in the 'Key relationships' section.
(Refer to the cross-section drawings in the 'Reference' section to see how many poles this motor has.)
- 4) With no dynamometer load, for drive frequencies of 40Hz, 50Hz, 60Hz, 70Hz and 80Hz, calculate the slip at each frequency. Record the results in the table opposite.
- 5) Set the drive frequency to 50Hz. Increase the dynamometer load to 50%, then 75%, then 90% and finally full load. Calculate the slip at each step. Record the results in the table.

3p motor drive	Speed	Slip
40Hz		
50Hz		
60Hz		
70Hz		
80Hz		

Slip vs drive frequency - no load

Dyno load	Speed	Slip
0%		
50%		
75%		
90%		
full		

Slip vs load - drive frequency = 50%



Over to you:

Explain these readings.

This image shows a single page of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page, leaving small margins at the top and bottom. There are no vertical margin lines, text, or other markings on the page.

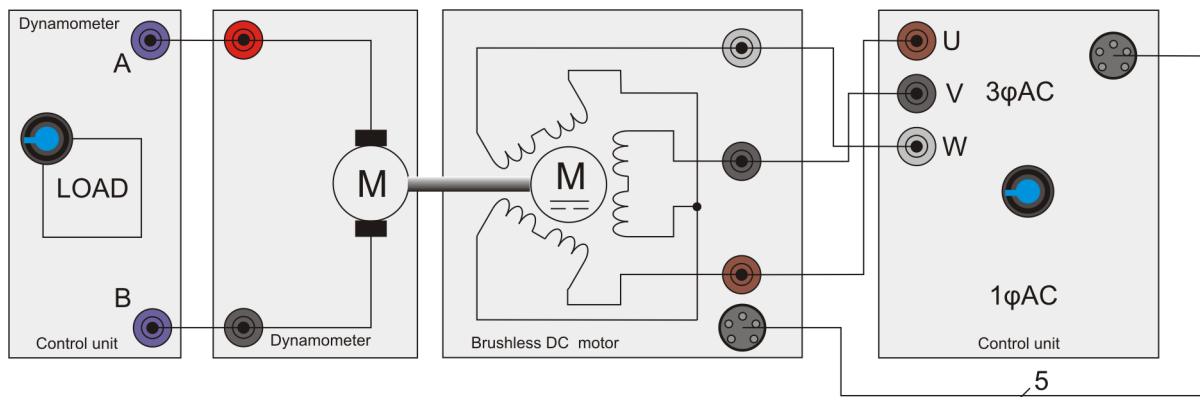
Worksheet 20

Brushless DC motor



Brushless DC motors have a great power output to weight ratio which makes them useful in weight sensitive applications like drones.

Their construction means that they need to be started at a slow speed and then ramped up to full speed.



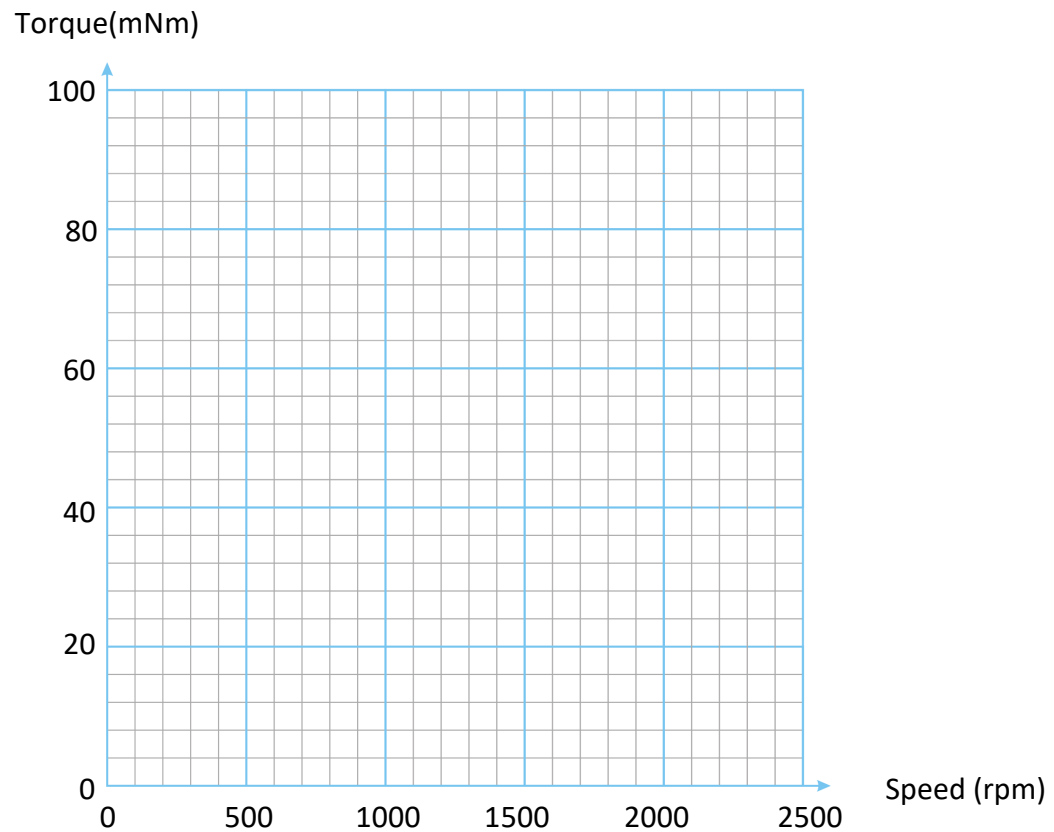
Over to you:

- 1) Set up the brushless motor, as shown in the diagram above. Don't forget to connect the brushless DC motor to the control unit with the 5-pin lead.
- 2) On your PC load 'Open Log_3phase.bat.'
- 3) With the initial frequency set to 40Hz, run the program to get a set of readings.
- 4) Repeat this step for drive frequencies of 50, 60, 70, and 80Hz.
- 5) On the next page, sketch the results.

Find out why a brushless DC motor is powered by a three-phase AC supply.

Worksheet 20

Brushless DC motor



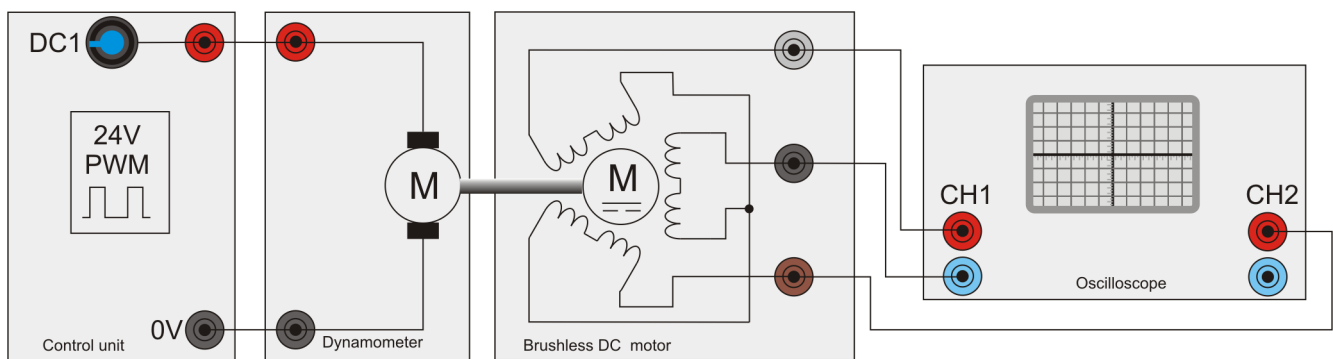
The effect of speed on torque for different values of output frequency.

Worksheet 21

Three-phase generator



We see small wind turbines everywhere.
The efficiency of three-phase over single-phase means that even small wind generators use three-phase machines to generate electricity.



Do not use a PC-based oscilloscope.

In this experiment, the brushless DC motor acts as a three-phase generator. It is mechanically linked to, and driven by, the dynamometer, which is supplied with a DC voltage.

Over to you:

- 1) Set up the brushless motor as shown in the diagram above.
- 2) On your PC load 'Open Control_DC.bat'.
- 3) Set a duty cycle of 40% on the DC1 output.
- 4) Press the 'RUN' button on the software.
- 5) Vary the DC output from 40% to 100% in 10% steps.
- 6) Make a note of the peak to peak output voltage from the brushless motor and fill in the table on the next page.
- 7) Sketch the three phase waveform on the next page.
- 8) How does the waveform relate to the motor RPM?

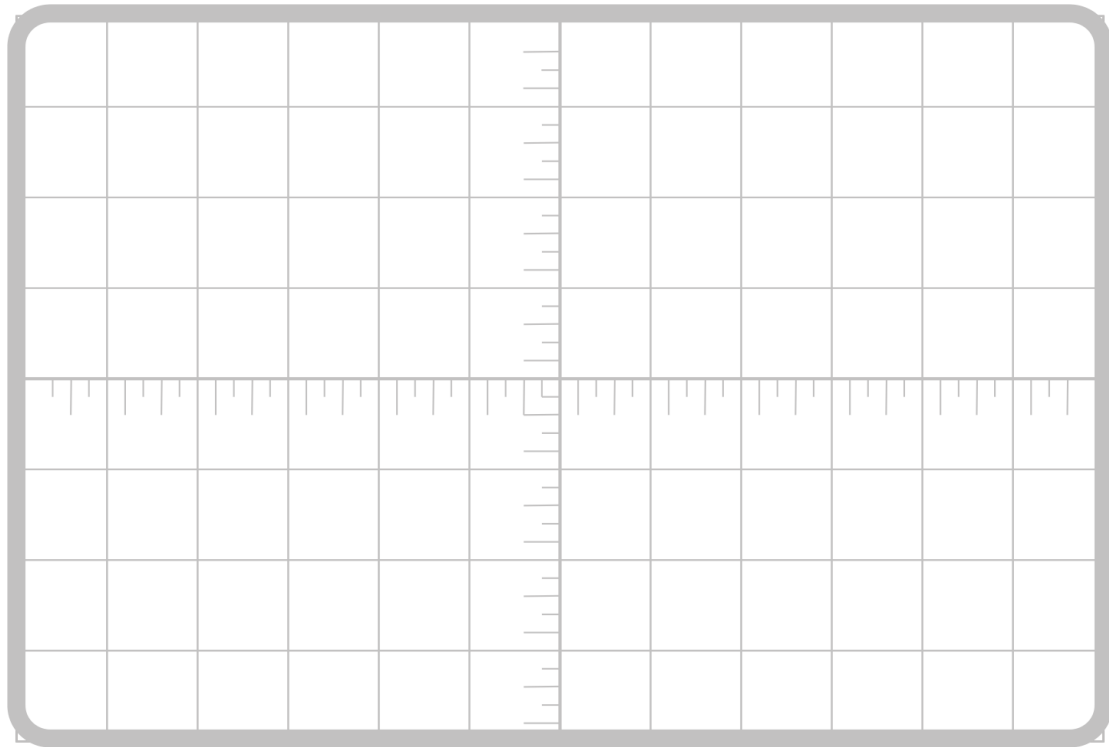
3p motor drive	Speed rpm	Vout pk-to-pk
40%		
50%		
60%		
70%		
80%		
90%		
100%		

So what?

The great thing about the brushless motor is the small size of the package and the fact that there are no brushes for ease of maintenance.

Worksheet 21

Three phase generator



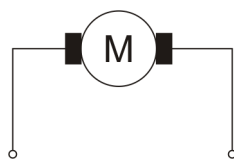
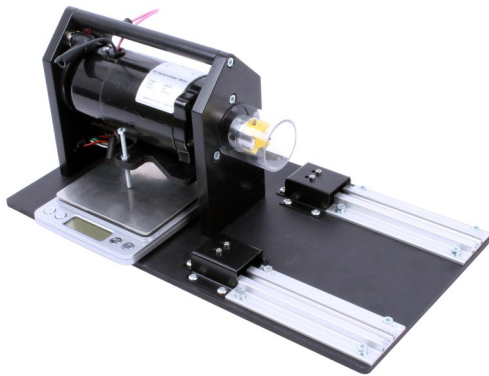
Over to you:

Use the tools available to investigate the efficiency of the brushless motor and compare it to that of the DC motor.

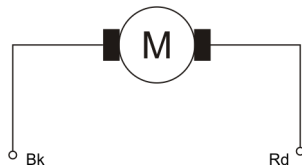
Machine information

Reference

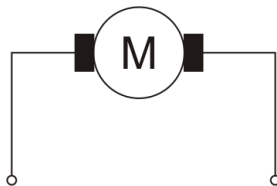
The dynamometer



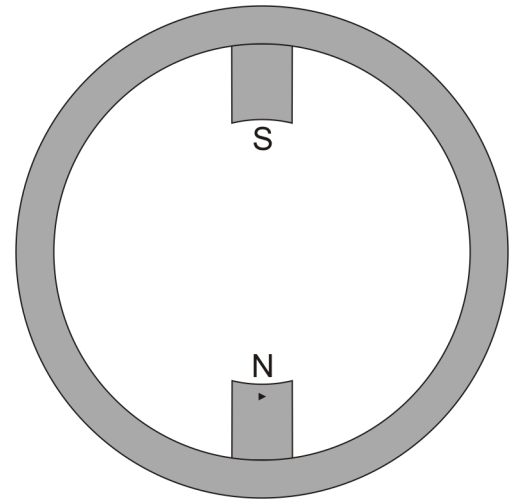
Conventional symbol



Actual circuit



Circuit in use



Stator winding circuit

Connection

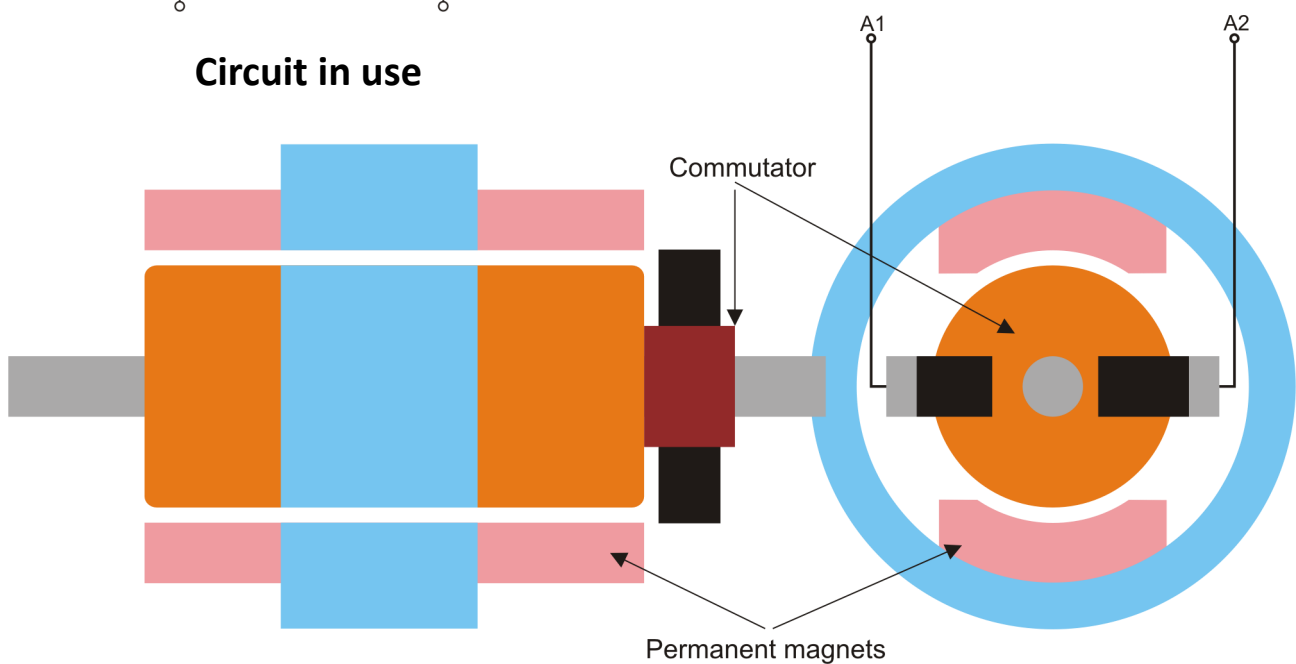
V+

V-

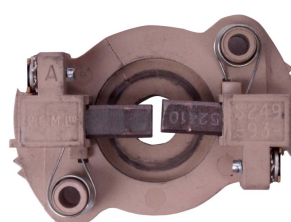
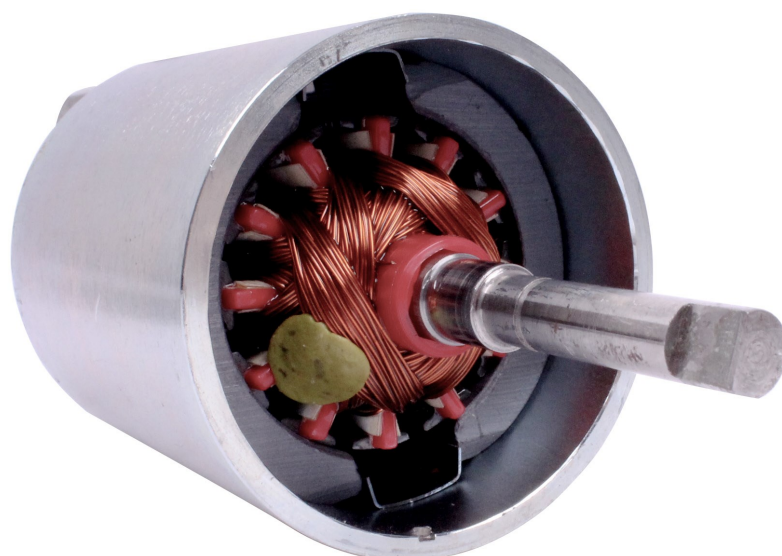
Colour

Red

Black

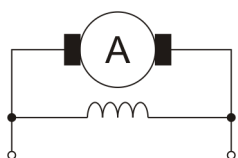


Construction

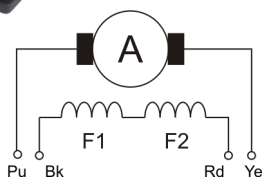


Reference

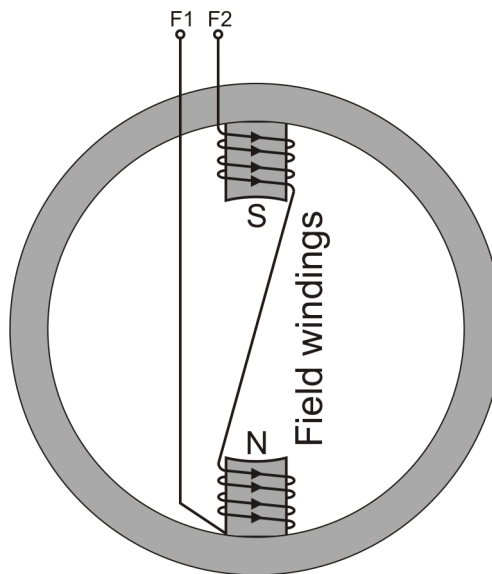
The shunt motor



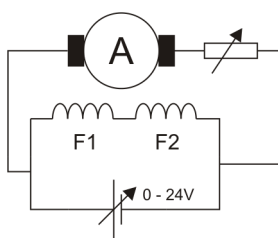
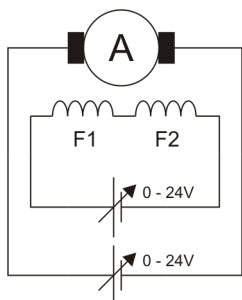
Conventional symbol



Actual circuit



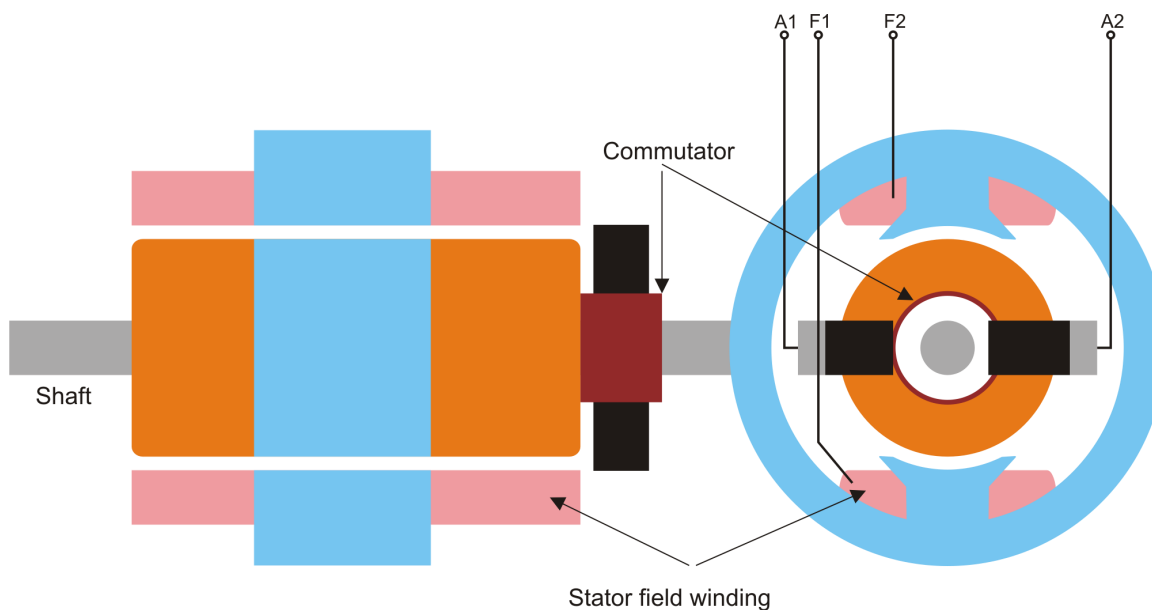
Stator winding circuit



Circuit in use

Connection
Armature
Armature
Field coil
Field coil

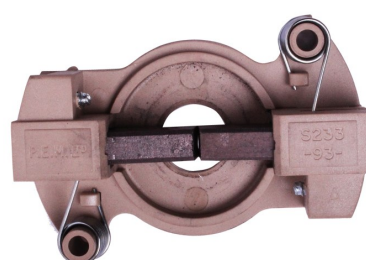
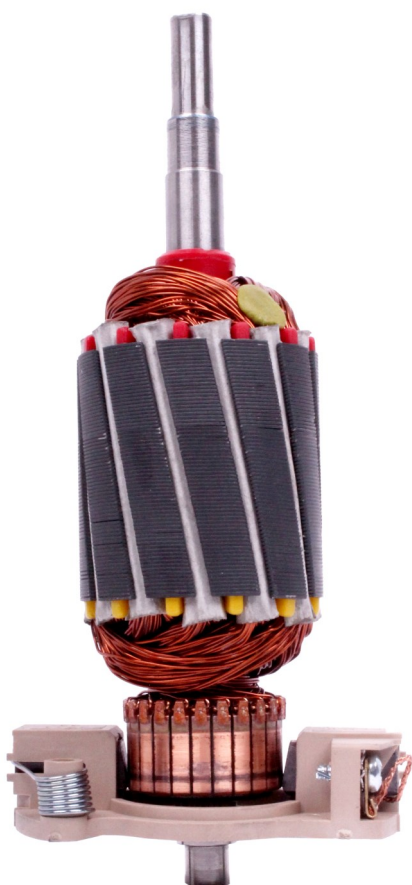
Colour
Purple
Yellow
Black
Red



Construction

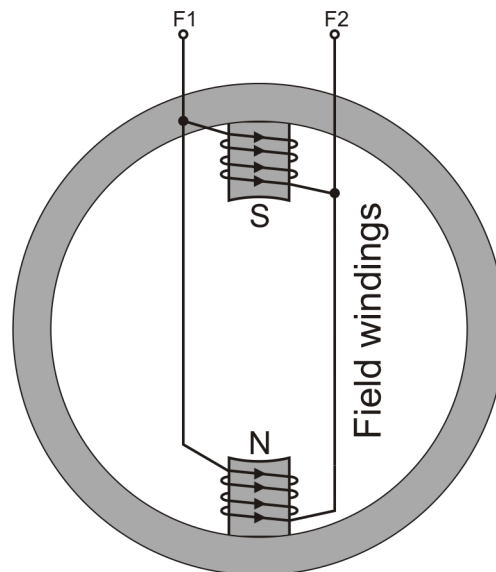
Reference

The shunt motor

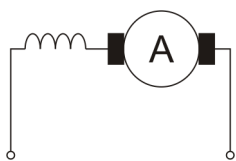


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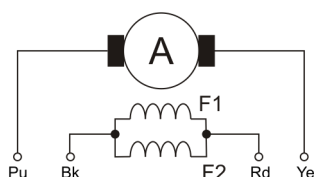
The series motor



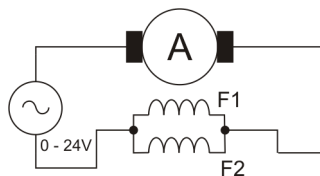
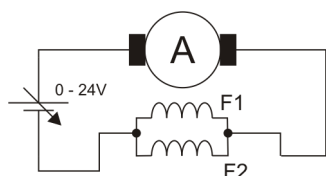
Stator winding circuit



Conventional symbol



Actual circuit



Circuit in use

Connection

Armature

Armature

Field coil

Field coil

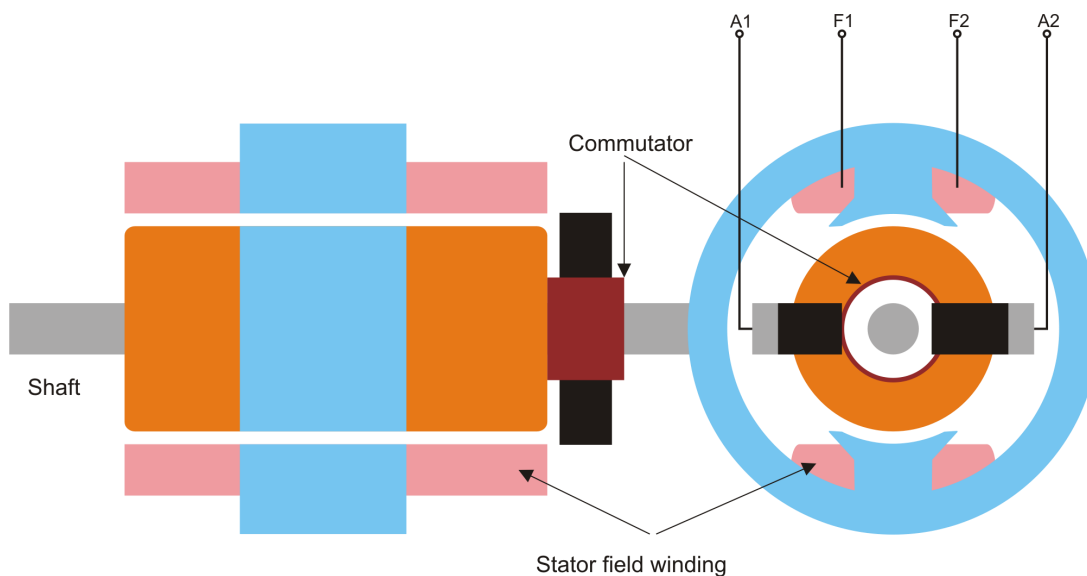
Colour

Purple

Yellow

Black

Red

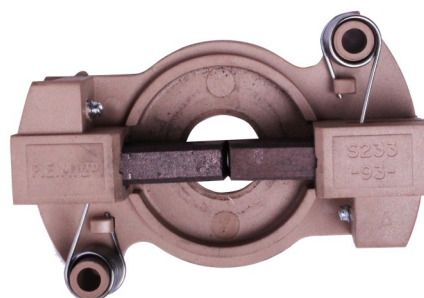
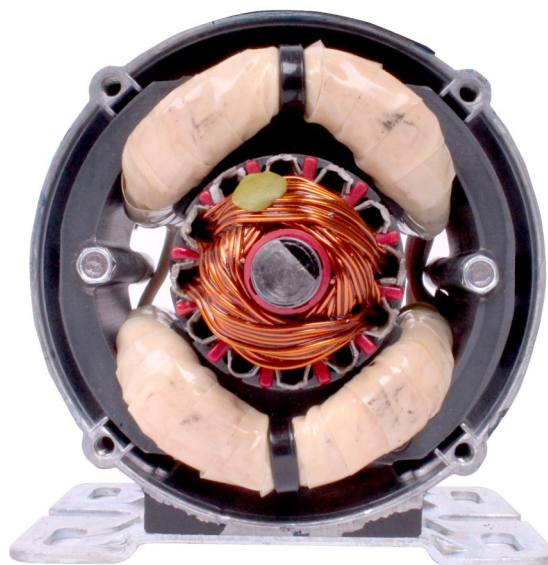


Construction

Reference

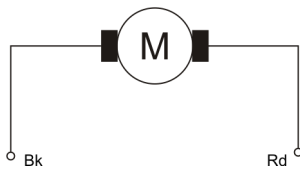
The series motor

MATRIX | ELECTRICAL
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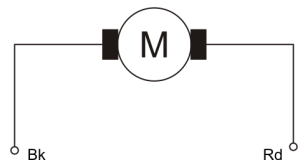


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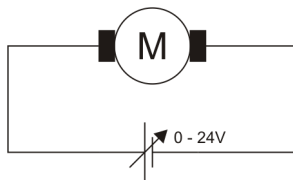
The DC motor



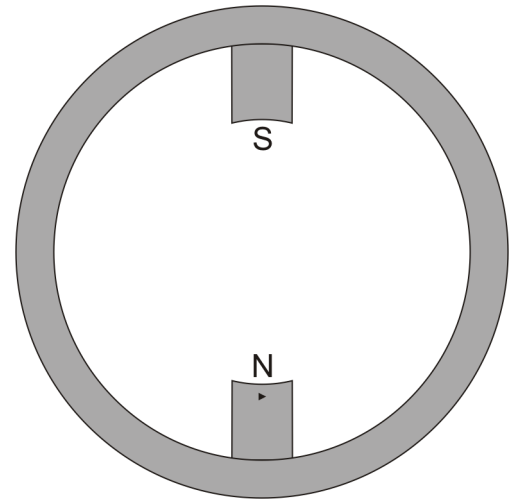
Conventional symbol



Actual circuit



Circuit in use



Stator winding circuit

Connection

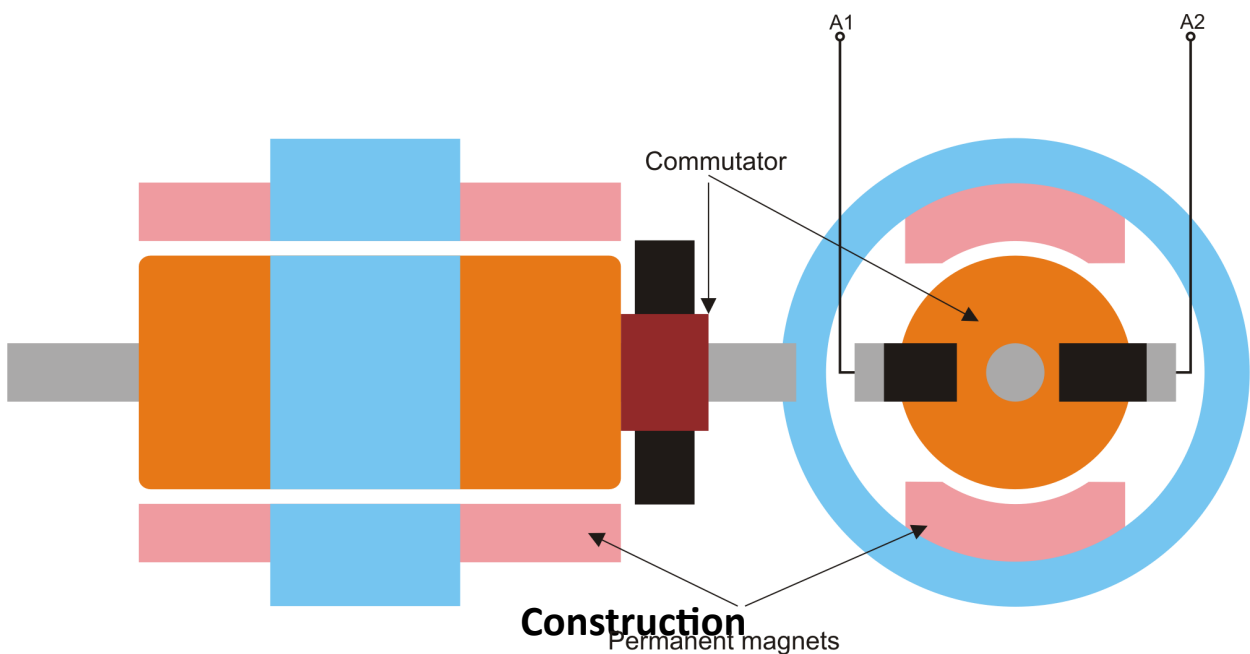
V+

V-

Colour

Red

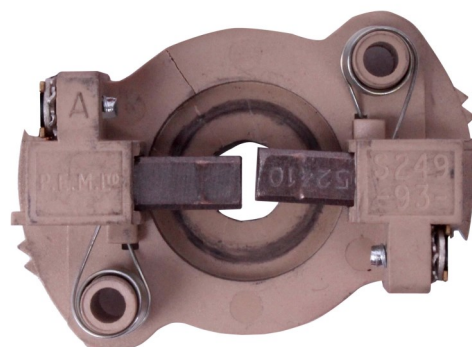
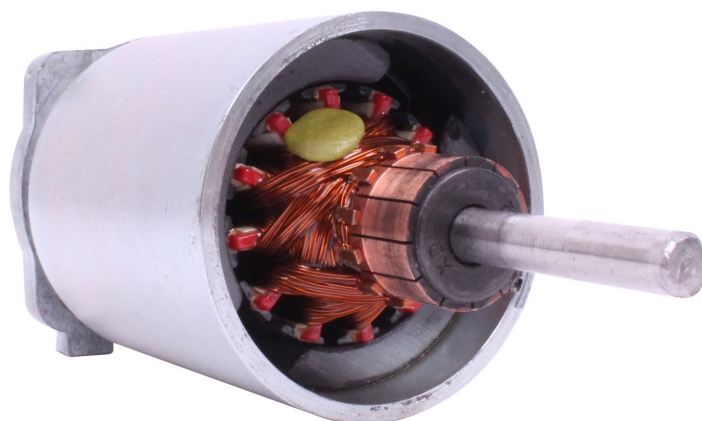
Black



Construction

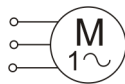
Reference

The DC motor

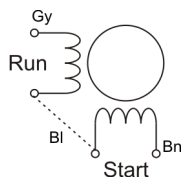


Reference

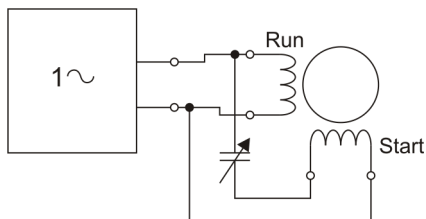
The single phase AC induction motor



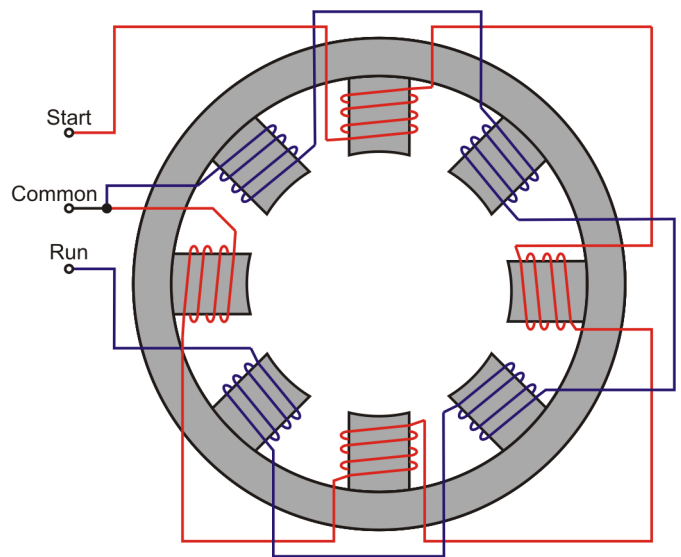
Conventional symbol



Actual circuit



Circuit in use



Stator winding circuit

Connection

Run

Start

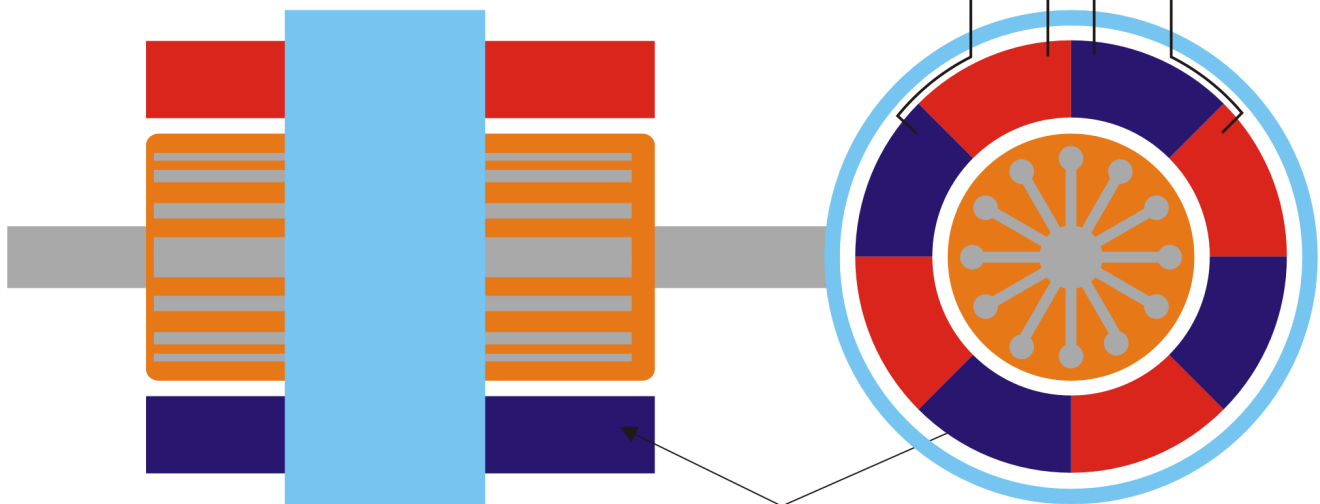
Common

Colour

Grey

Brown

Blue



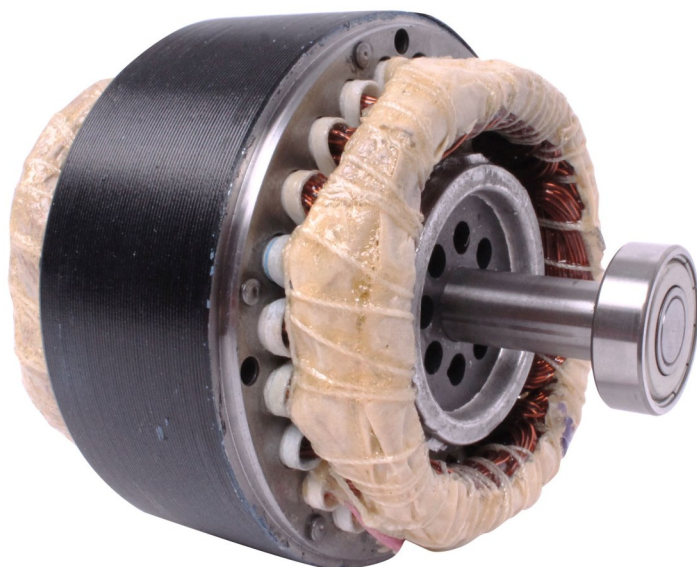
Stator field winding

Construction

Reference

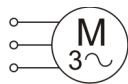
The single phase AC induction motor

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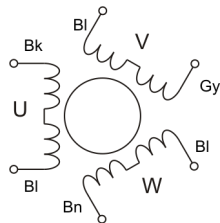


Reference

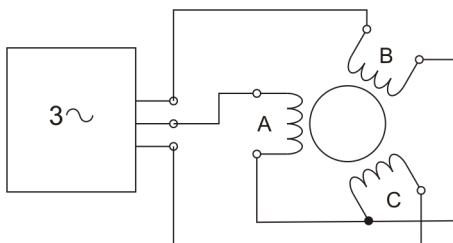
The three phase AC induction motor



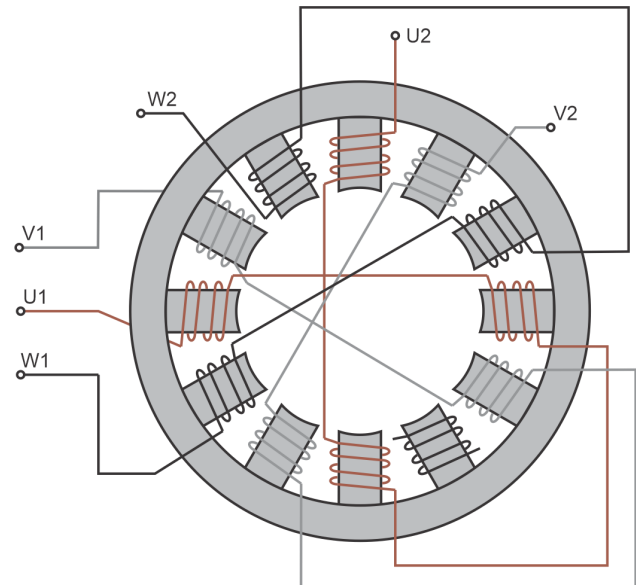
Conventional symbol



Actual circuit



Circuit



Stator winding circuit - 2 pole pairs

Connection	Colour
Phase U1	Black
Phase U2	Blue
Phase V1	Grey
Phase V2	Blue
Phase W1	Brown
Phase W2	Blue



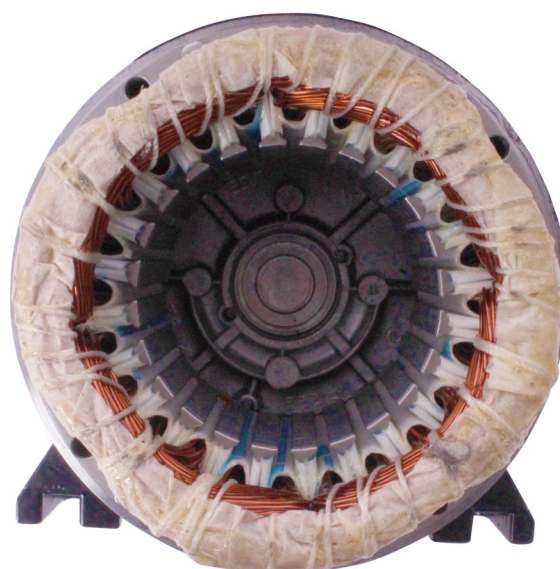
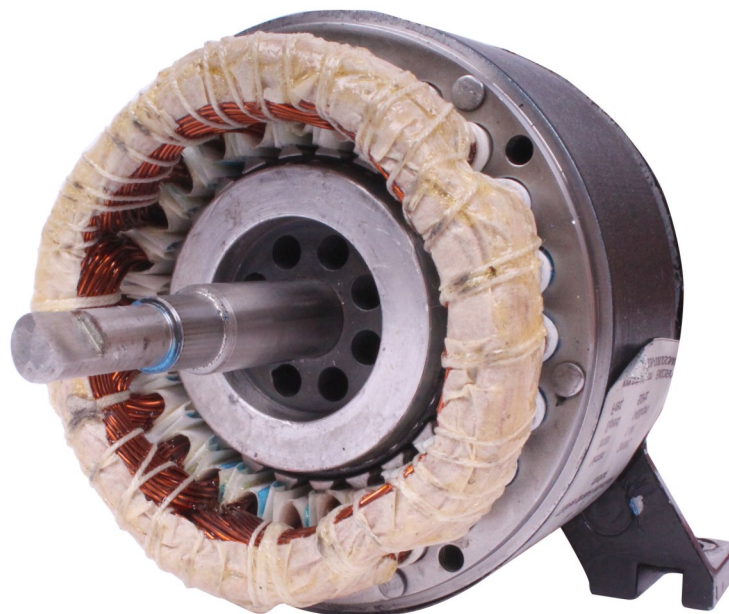
Stator field winding

Construction

Reference

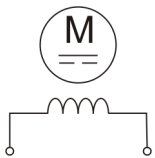
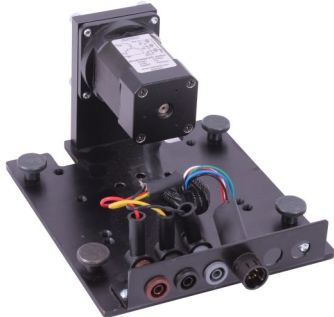
The three phase AC induction motor

MATRIX | ELECTRICAL
MACHINES

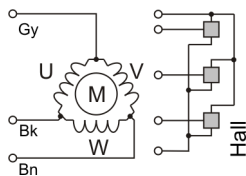


Reference

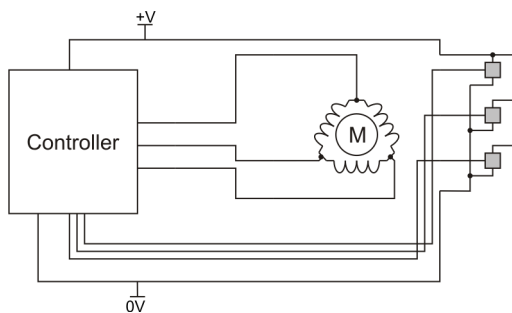
The Brushless DC motor



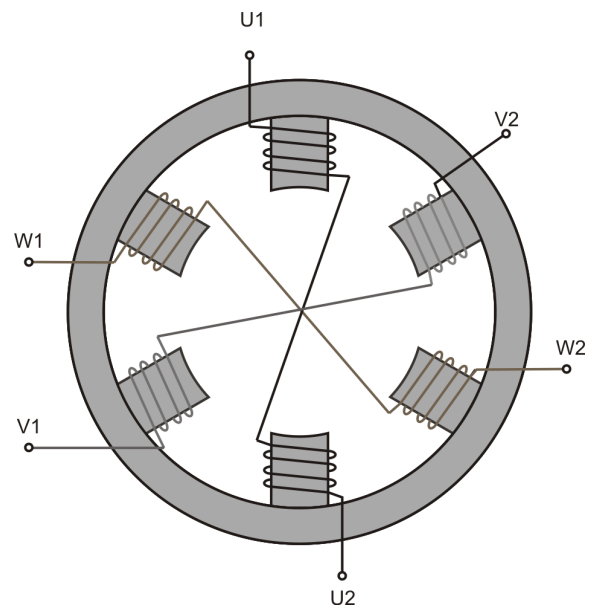
**Conventional
symbol**



Actual circuit



Circuit in use



Stator winding circuit

Connection

Phase U

Phase V

Phase W

Colour

Black

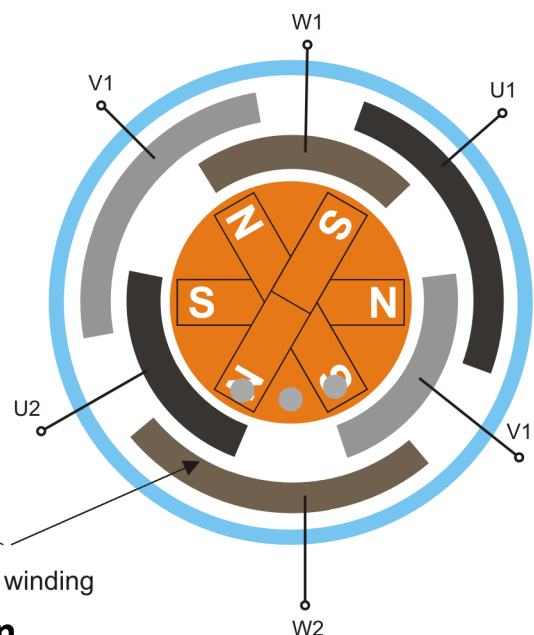
Grey

Brown



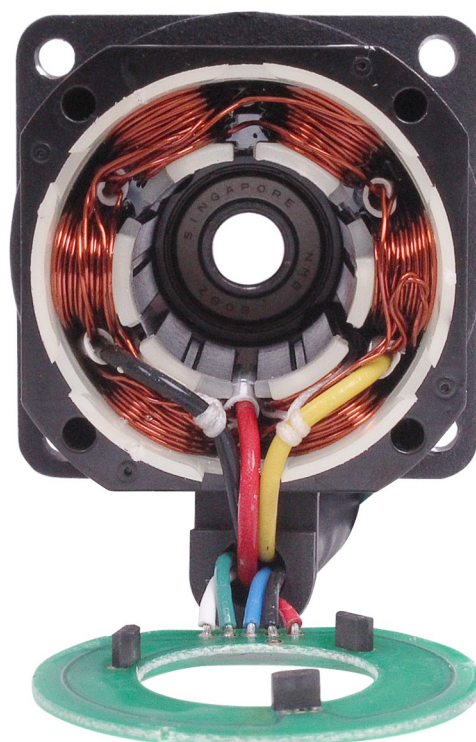
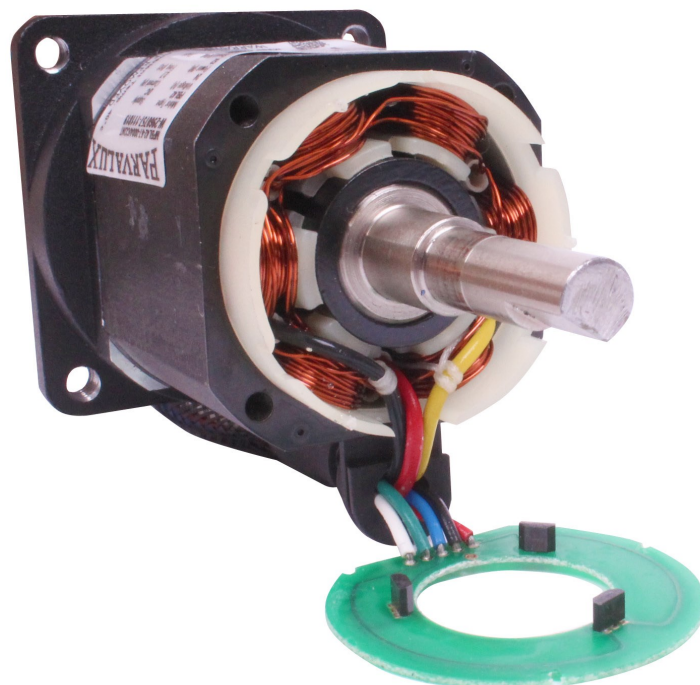
Stator field winding

Construction



Reference

The Brushless DC motor



Package information

Understanding the system

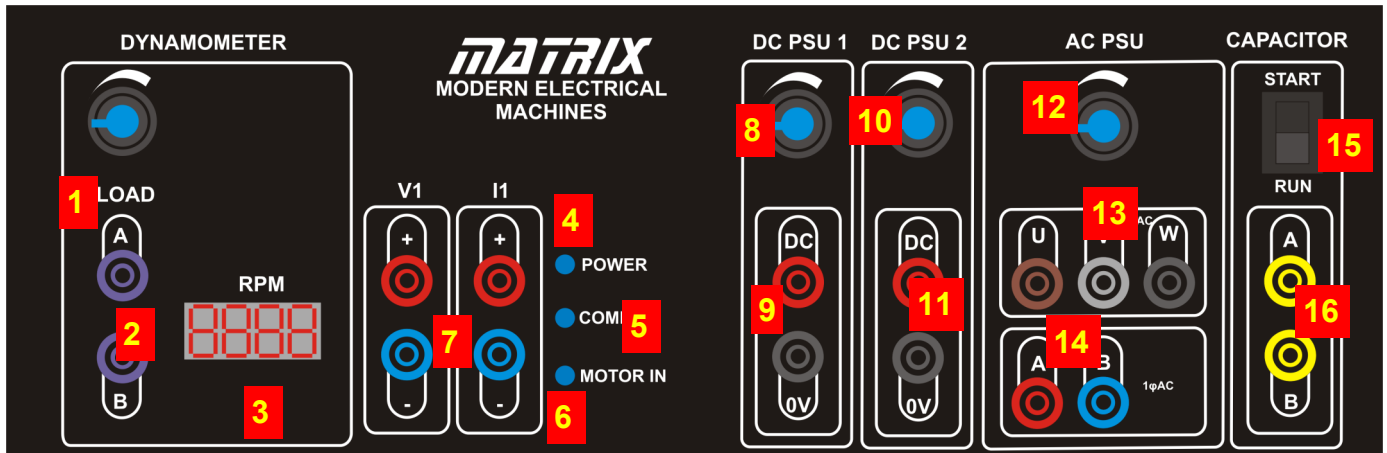


The system consists of a number of 24V electrical machines, a control unit, software applications for driving the control unit and a set of worksheets. The photograph above shows these parts. They are:

- 1) The dynamometer and cradle which connects to the control unit using a 25way D-type lead
- 2) Balance
- 3) Motor under test - in this case a shunt wound motor
- 4) The control unit which connects to a PC using a USB lead.
- 5) A series wound motor
- 6) Single-phase AC induction motor
- 7) Brushless DC motor
- 8) DC motor
- 9) Three-phase AC induction motor
- 10) The software application running on a PC

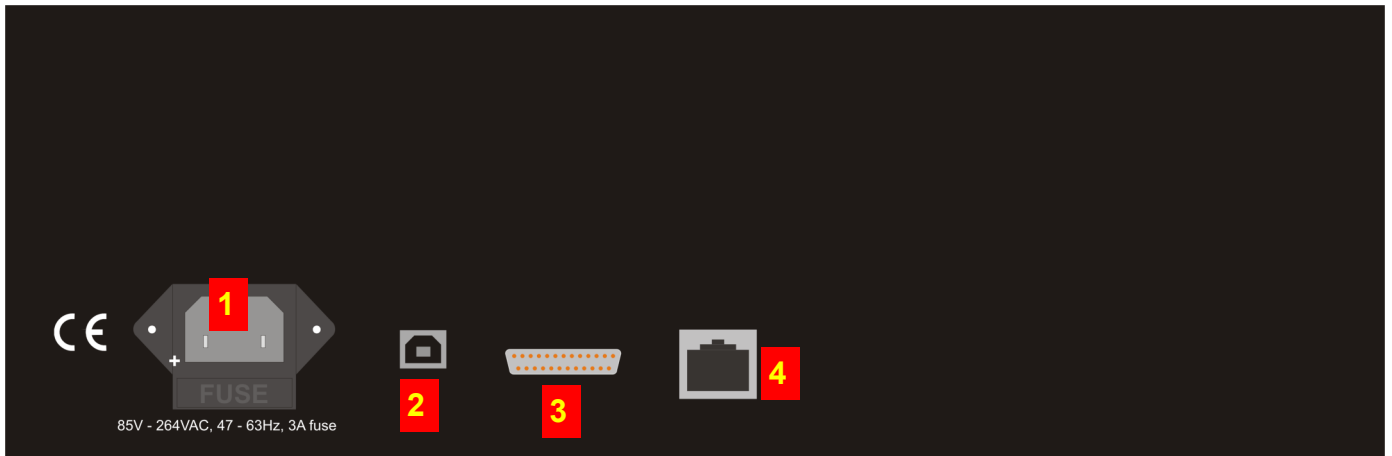
Understanding the control unit

Note - manual controls are overridden as soon as the unit is plugged into a computer.



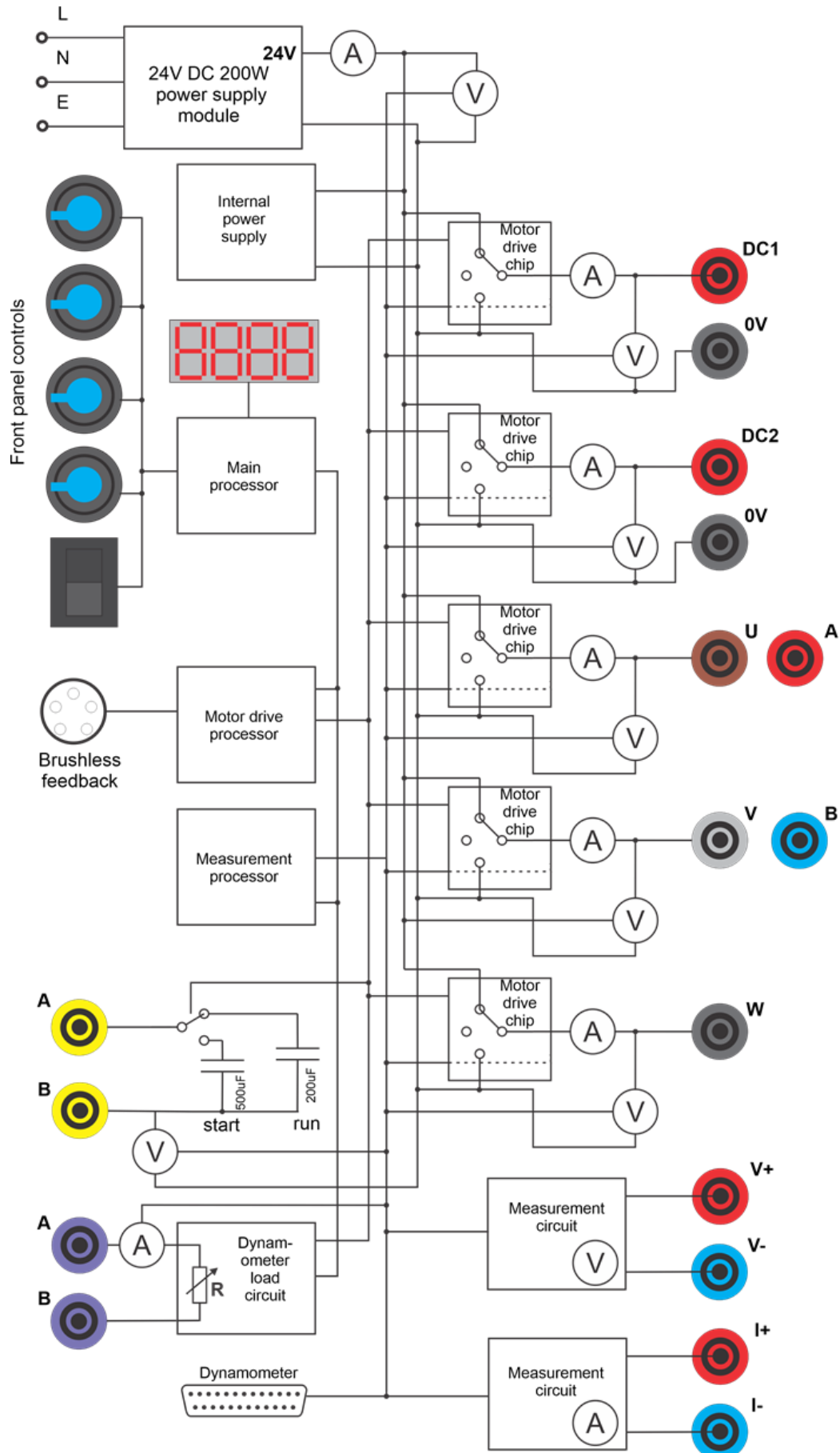
- 1) The dynamometer resistance: use this to control the effective resistance placed across the dynamometer: low electrical resistance means a large mechanical resistance, and high electrical resistance means low mechanical resistance
- 2) The dynamometer connections
- 3) The speed of the motor in Revolutions Per Minute - RPM.
- 4) The power LED which shows the control unit is powered up.
- 5) The COMMS LED which is lit when the PC software has communication with the control unit.
- 6) The 'Motor In' LED which indicates that a machine is physically connected to the dynamometer.
- 7) The internal ammeter and voltmeter connections
- 8) The DC 1 Supply output control.
- 9) The DC 1 connections.
- 10) The DC 2 Supply output control.
- 11) The DC2 connections.
- 12) The AC frequency control
- 13) The three-phase supply connections
- 14) The single phase supply connections
- 15) The capacitor mode selector switch: this controls the internal value of capacitor connected to the A and B terminals. There are two values: START, RUN.
- 16) Variable capacitance terminals.

Understanding the control unit



- 1) The Mains input plug - the unit takes 240V or 110V
- 2) The USB connector
- 3) A 25 way D-type connector which is used to connect the Control unit to the Dynamometer
- 4) RJ45 LAN/internet connection socket.

Control unit schematic



Control unit description

Please refer to the block diagram on the previous page.

The control unit shipped with the Matrix Modern Electrical Machines system is one of the most up to date in the World. Inside the unit there are three separate processors: a main processor handling all user interface and communication tasks, a motor drive processor handling all the high current outputs and dealing with all waveform and timing systems, and a measurement processor. These three processors use buses to communicate between themselves and between the different electronic circuits in the unit.

A key feature of the control unit is that almost every quantity in the unit can be measured. On the schematic you can see that there are 16 separate ammeters and voltmeters in the system. This gives the instrumentation software and the user lots of options when displaying what is happening in an electrical machine system. The measurement of each quantity takes place thousands of times per second and can be processed by PC software applications to display a quantity or a waveform.

The motor drive chips are all low voltage drop FET based units. As you can see from the schematic all the outputs are digital 24V outputs. Simple pulse width modulation algorithms are used to vary the effective output power on the DC outputs. On the AC outputs Pulse width modulation is again used but with a more advanced pseudo-sine with third harmonic wave algorithm which varies the output power sinusoidally over the period of the output waveform. This technique is used by the more advanced motor controllers in industry. Older, and perhaps cheaper, motor driver systems sometimes use a simple digital output waveform for driving

three phase induction motors where the three outputs are simply digital outputs phase shifted by 120 degrees. This digital output is also available in some software applications shipped with the system so that students can investigate the efficiency of each method.

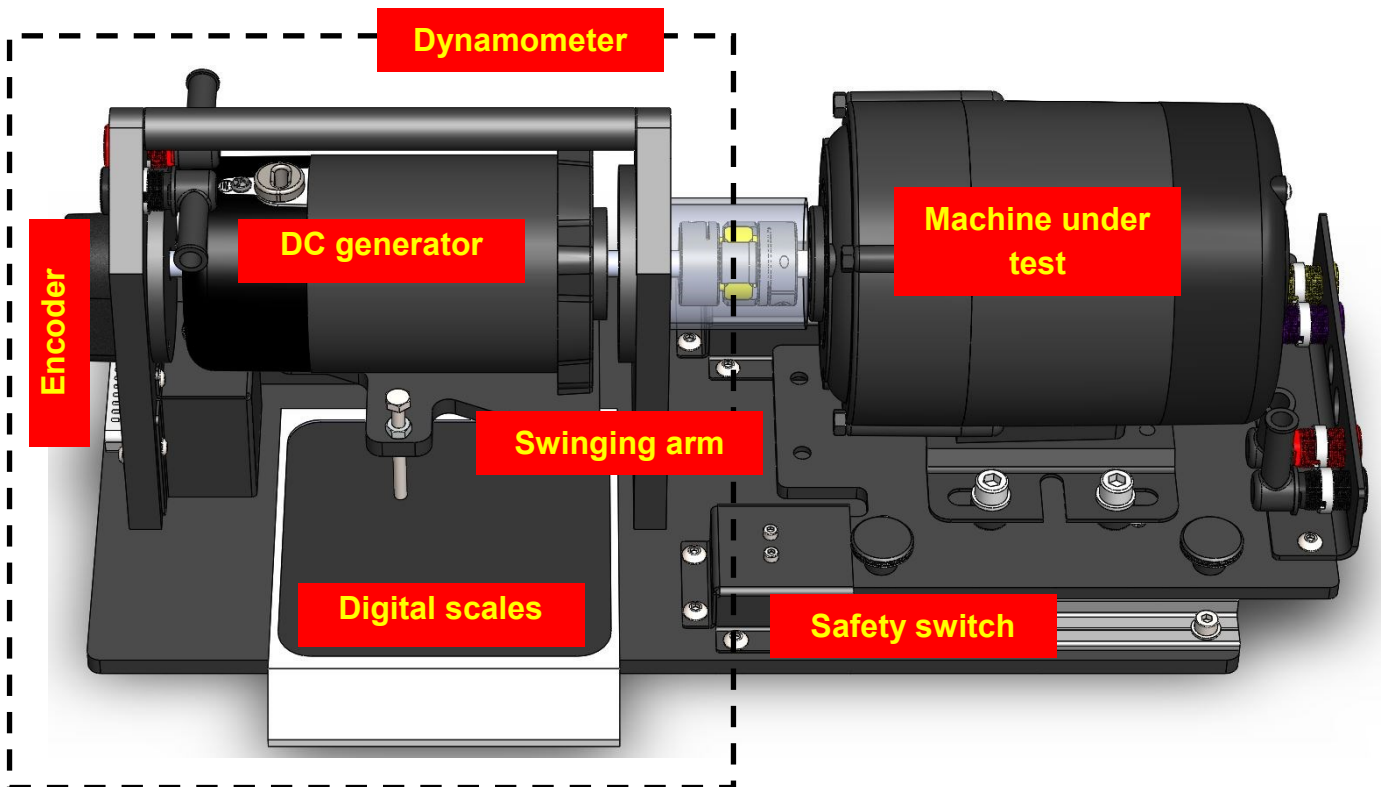
The motor driver chip outputs can be placed in one of three states: 24V, 0V and open circuit. This allows for different drive strategies when generating waveforms for driving motors. As part of the learning package students investigate PWM for driving DC motors, and Pseudo-sine waves for driving single phase AC motors. The unit also performs more complex six step pseudo-sine wave generation for driving the three phase motor and this can be examined with the internal multi channel oscilloscope as well as an external oscilloscope. To facilitate this when in AC mode a small pulse is given on the DC1 output which allows an external oscilloscope to be triggered to capture the various waveforms.

Note that most of the internal ammeters and voltmeters are on the Driver board in the unit. The topmost ammeter and voltmeter in the block diagram monitor power to the Driver board and this is displayed in the applications.

The unit includes two values of capacitor with a simple relay for start / run investigation for single phase induction motors.

The unit also includes a FET based load for the dynamometer whose effective resistance is controlled by software.

Understanding the dynamometer



A dynamometer is an instrument that directly measures the force produced and speed of a rotating machine (the motive force). Torque and power can be calculated from the measured force and speed. In our case the mechanical rotation is produced by one of the DC or AC electrical motors. This Dynamometer is an absorption type swing arm / balanced beam dynamometer, where the motive force is used to drive a DC generator with a variable resistance load attached. The resulting force can be measured in one of two ways:

- A digital scale (shown in the image above) can be used to measure the effective vertical force on the scale and it gives a reading in Kilograms. This can be converted into newtons and newton metres - see below.
- A load cell (behind the dynamometer and not shown in the image above) connected to the control box gives the same infor-

mation - give or take a few percent.

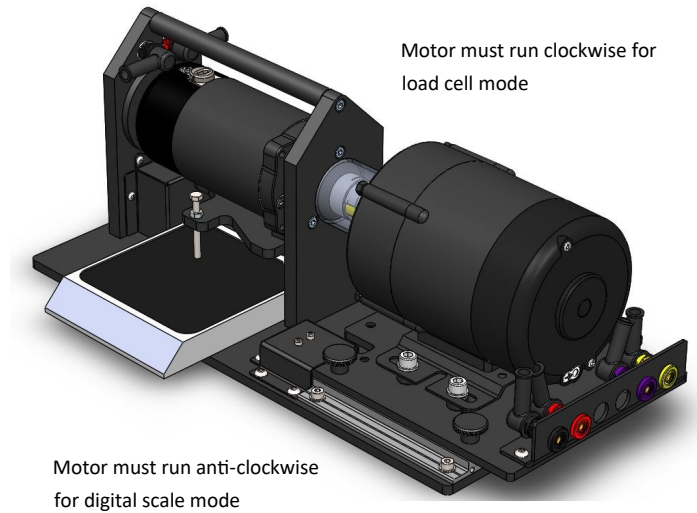
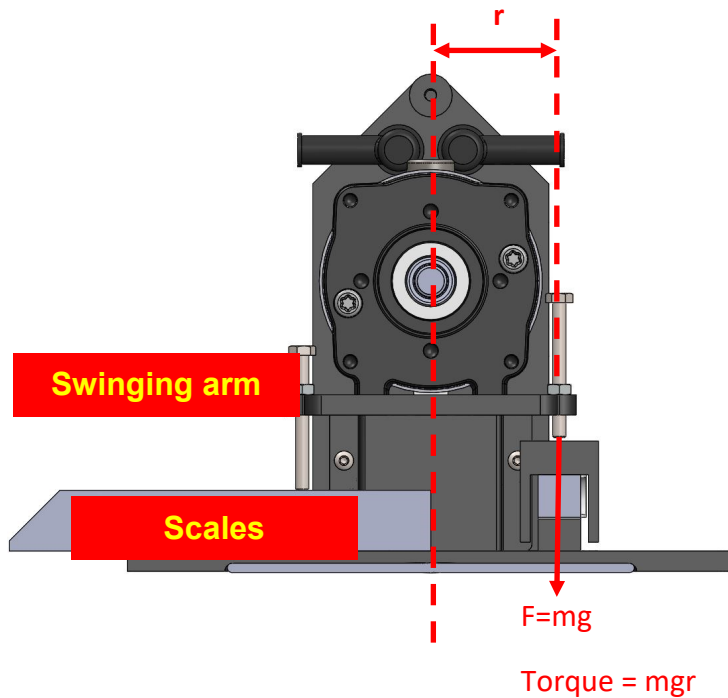
Note that the rotation of the dynamometer dictates whether the balance or the load cell is used. Controlling the direction of motion of each machine is discussed below.

The encoder on the shaft of the dynamometer allows the control unit to detect the rotational speed. This is displayed on the control unit in revolutions per minute (rpm) and on the software application.

Machines under test are coupled to the dynamometer using a coupling which is housed in a plastic tube to prevent clothes and hair getting caught in the mechanism. Two microswitches are provided on the dynamometer - unless a machine under test is in place the control unit will not activate.

Reference

Measuring torque



The dynamometer rotates in the same direction as the machine under test. It provides a mechanical resistance for the machine under test. It also generates a voltage and - if a resistance is placed across the Dynamometer terminals - it produces a current.

If voltage and current flow then power is being generated - work is being done. The more power generated by the Dynamometer, the more mechanical power has to be generated by the machine under test.

We test electrical machines to understand their properties so we know when to use the various types of machine. The way we test them is to vary their speed and the mechanical power they need to generate. The dynamometer and the Control unit allow us to do this.

The Dynamometer is made up of a DC motor and a cradle. The DC motor also acts as a DC

generator. The cradle suspends the DC machine in two bearings that allow the body of the machine to rotate. The force on the load cell (or digital scale when the motor is running anti-clockwise) creates a weight on the load cell or scale (which represents mass). If the swing arm is perfectly balanced and horizontal when it is at rest, the force produced on the load cell or digital scale is $\text{Force} = \text{mass} \times 9.81\text{m/s}^2$. The torque can be calculated from the formula $\text{Torque} = \text{Force} \times \text{Distance}$. In this case, the distance is from the centre of rotation of the generator to the centre line of action of the swing arm. **For the Matrix dynamometer, $r = 38.12\text{mm}$**

More discussion on calculations is given below.

Software Information

Equipment: modes of use



The Modern Electrical Machines equipment can be used in two ways:

Manual mode - no software

When no USB lead is plugged into the unit then the control unit is in manual mode. This allows users control of the DC and AC power supply outputs using the potentiometers on the front of the unit. The capacitor start / run is controlled by the front panel switch and the speed of the dynamometer is displayed by the 7 segment display. Manual mode is useful when teaching students the basics of electrical machine control and will be useful when used with true RMS multimeters to measure voltages and currents.

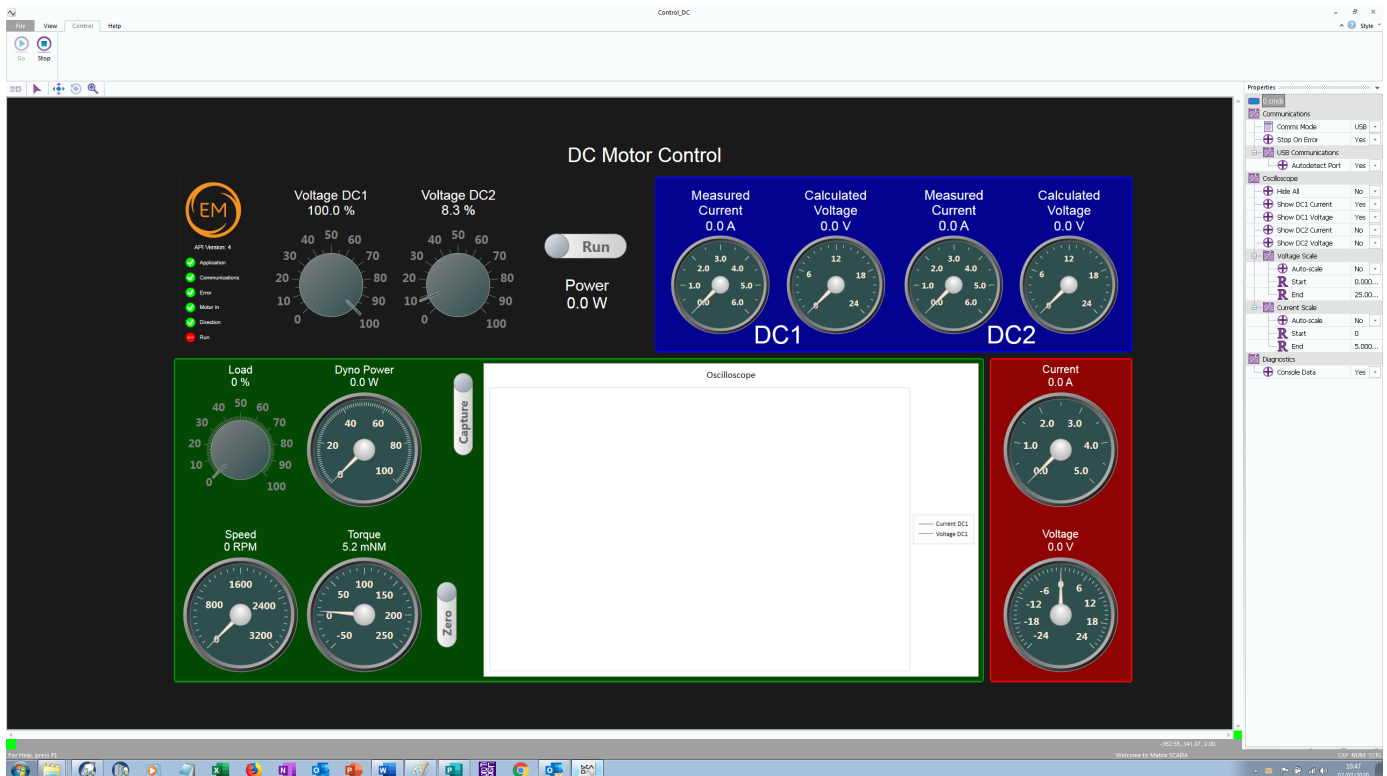
In Manual mode we make use of a small balance to measure torque. The swinging arm of the Dynamometer has two modes of use: when rotating counter-clockwise it presses down on

the balance. When rotating clockwise it presses down on the load cell for computer based measurement. Users simply reverse the direction of motion of the machine under test to change rotational direction.

Software mode

When the USB lead is plugged in to the Control unit the front panel controls are disabled. Six separate software applications are available to the user for carrying out experiments with the different machines.

Understanding the software



Applications

Six different PC based applications are shipped with the unit. Each of them is a self contained executable '*.BAT' file. Drivers for the Control unit will need installing - the applications will not. These applications are:

Open Control_DC.bat: for direct DC measurement for DC motors.

Open Log_DC.bat: for gathering speed torque data and logging the results for DC motors.

Open Control_1Phase.bat: for direct measurement for single phase AC induction machines.

Open Log_1Phase.bat: for gathering speed torque data and logging the results for single phase AC induction machines.

Open Control_3Phase.bat: for direct measurement for three phase induction and brushless DC motors.

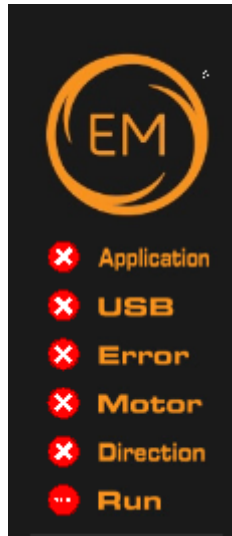
Open Log_3Phase.bat: for gathering speed torque data and logging the results for three phase induction and brushless DC motors.

These are explained below.

An API for use with LabView or MATLAB is also available.

Naming of these applications may vary slightly as updates are released.

Software flags



Each application has a set of software flags which are displayed on the top left hand side. These are:

Application: green when the application is in Play mode.

USB: Green when there is a USB connection between the control unit and the PC.

Error: red when there is an Error in the control unit. Most often this happens due to an over current error. The unit is capable of providing 100 watts of power. When this is exceeded the unit shuts down. In this case you should lower the output voltage and try again.

Motor: green when the microswitches in the Dynamometer are activated by the presence of a machine under test. The unit will not run unless a machine under test is present.

Direction: green when the direction of rotation is clockwise which will press down on the

torque sensor.

Run: green when the run switch is triggered.

Understanding the software



There are two types of software application supplied with the Electrical Machines course:

- Manual control
- Automatic

Manual control applications allow you to manually set all of the parameters inside the control box. Automatic applications allow you to automatically take multiple sets of readings for producing speed torque graphs. This page and the following 5 pages show you the screen layouts and controls.

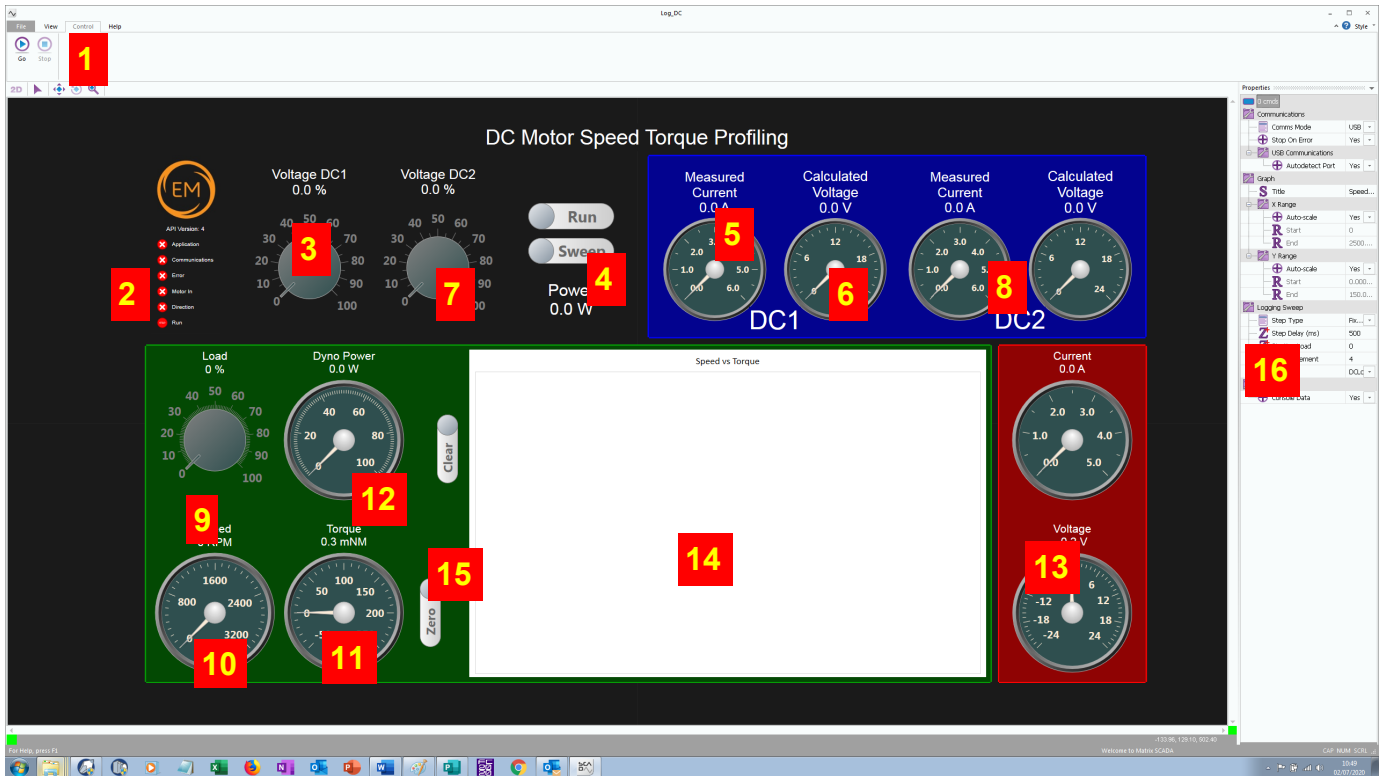
The file name for this program is 'Open Control_DC.bat' and it is intended for manual DC measurements.

- 1) Program control - hit 'PLAY' to start
- 2) Flags for App running, USB comms and Motor in place etc. The box will not start until all show green ticks.

- 3) DC1 output - shows PWM duty cycle for DC output 1 with voltage and current.
- 4) Run / Stop switch - needs pressing to turn outputs on
- 5) DC2 output - shows PWM duty cycle for DC output 2
- 6) Meter for Current terminals
- 7) Meter for Voltage terminals
- 8) Dynamometer load as a %
- 9) Dynamometer speed in RPM
- 10) Torque in mNm
- 11) Dynamometer power in watts
- 12) Oscilloscope
- 13) Properties for the program and scope.

Reference

Automatic DC software



The file name for this program is 'Open Log_DC.bat'

- 1) Program control - hit 'PLAY' to start
- 2) Flags for App running, USB comms and Motor in place. The box will not start until all three show green ticks
- 3) DC1 output - shows PWM duty cycle for DC output 1
- 4) Sweep - takes a set of readings sweeping the Dynamometer from 0-% to 100%
- 5) RUN and SWEEP switches.
- 6) DC2 output - shows PWM duty cycle for DC output 2
- 7) Meters for DC 1 - RMS values
- 8) Meters for DC 2 - RMS values
- 9) Dynamometer load as a %
- 10) Dynamometer speed in RPM

11) Torque in mNm

12) Dynamometer power in watts

13) Internal ammeter and voltmeter V1 and I1

14) On screen graph of plot data

15) Graph / log clear button

16) Program properties

When the Run button is pressed the control box will - at the specified voltage on DC1 and DC2 take readings from 0 load to 100% load in 2% increments. The results will be stored in the file LOG_DC1.CSV for plotting in Excel.

Whilst the readings are being taken the on screen graph will show an approximate plot so that you can be sure you are getting valid data. Up to 8 data sets can be captured and displayed at one time.

Single phase AC manual



The file name for this program is 'Open Control_1Phase.bat'

- 1) Program control - hit 'PLAY' to start
- 2) Flags for App running, USB comms and Motor in place. The box will not start until all three show green ticks
- 3) Frequency of output
- 4) AC voltage output
- 5) SINE/DIGITAL: Sine wave or square wave output.
- 6) CAP START/CAP RUN: selects the internal capacitor value.
- 7) RUN switch - needs pressing to turn outputs on.
- 8) Meters for the outputs - RMS values
- 9) Dynamometer load as a %

- 10) Dynamometer speed in RPM
- 11) Torque in mNm
- 12) Dynamometer power in watts
- 13) REAL V / EFFECTIVE V: shows the voltage on the graph in real terms or effective terms.
- 14) PHASE / TIME: shows X axis in degrees or in mS
- 15) CAPTURE: captures a waveform
- 16) Oscilloscope / graph plot area
- 17) Internal ammeter and voltmeter V1 and I1
- 18) Properties control

Single phase AC automatic



The file name for this program is 'Open Log_1Phase.bat'

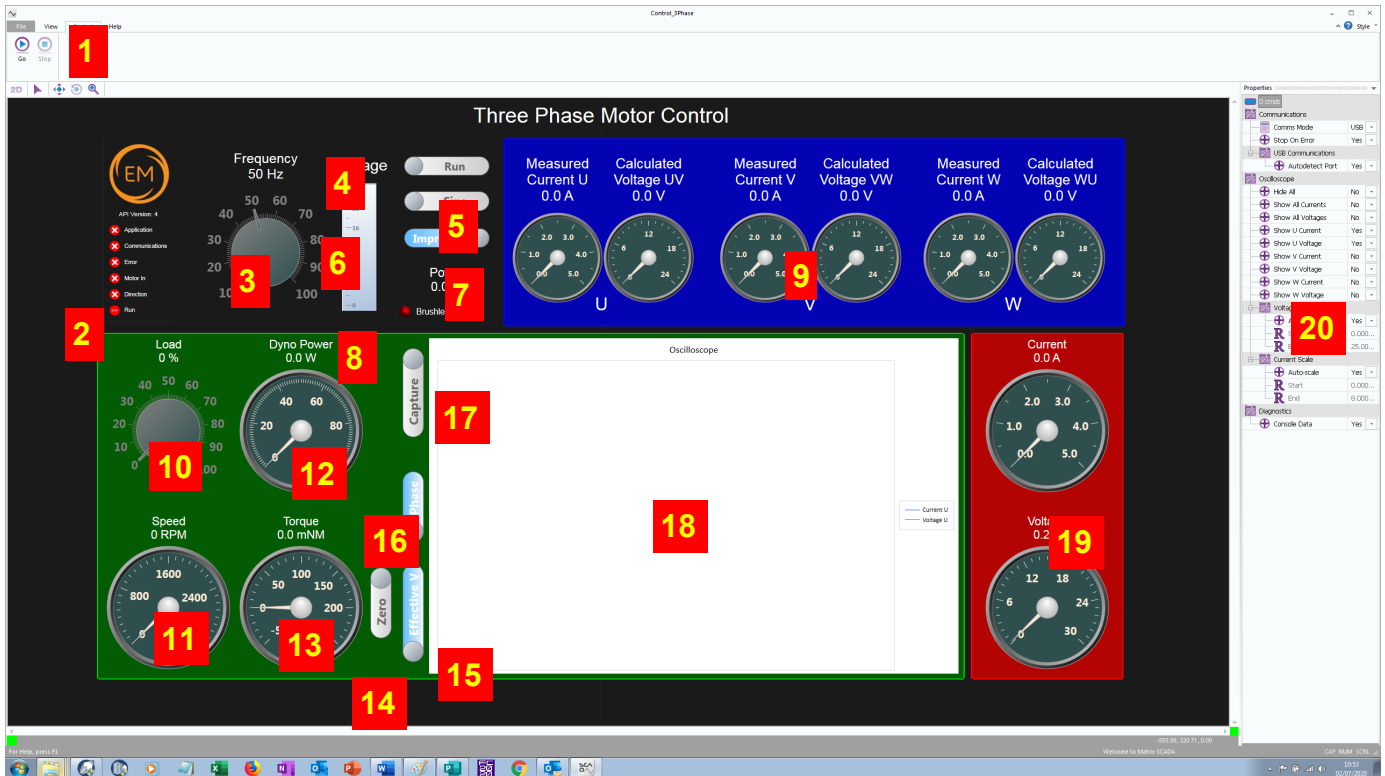
- 1) Program control - hit 'PLAY' to start
- 2) Flags for App running, USB comms and Motor in place. The box will not start until all three show green ticks
- 3) Frequency of output
- 4) Voltage of output
- 5) Run switch - starts automatic logging of data
- 6) Drivemode - default is pseudo-sine, on is trapezoid
- 7) CAP START / RUN switch controls the value of internal capacitor on the variable capacitor terminals
- 8) SWEEP: starts sweep function
- 9) Meters for the output - RMS values
- 10) Dynamometer load as a %

- 11) Dynamometer speed in RPM
- 12) Torque in mNm (Zero switch is used on start up)
- 13) Dynamometer power in watts
- 14) Internal ammeter and voltmeter V1 and I1
- 15) On screen graph of plot data
- 16) Graph / log clear button
- 17) Torque zero button
- 18) Properties

When the SWEEP button is pressed the control box will - at the specified frequency output take readings from 0 load to 100% load in 2% increments. The results will be stored in the file LOG_1phase.CSV for plotting in Excel.

Whilst the readings are being taken the on screen graph will show an approximate plot so that you can be sure you are getting valid data.

Three phase AC manual



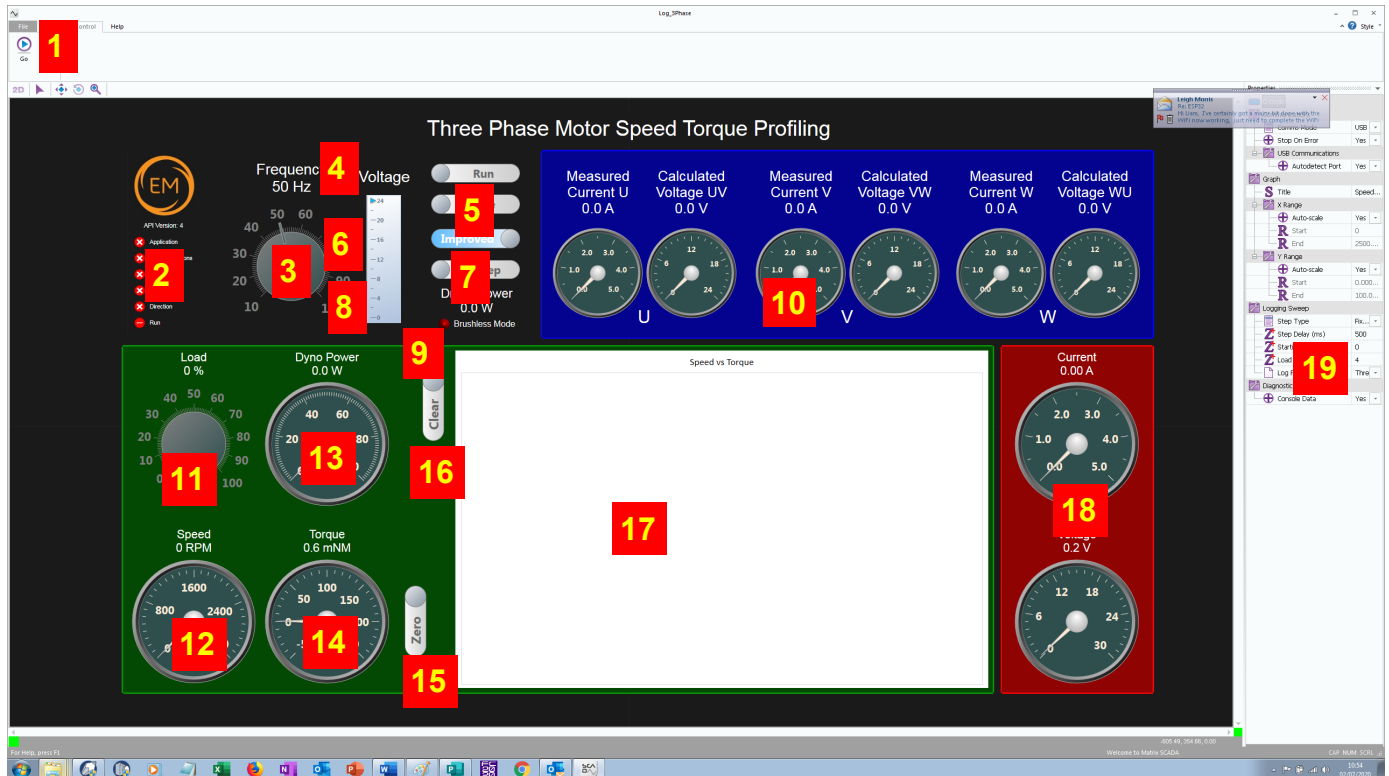
The file name for this program is 'Open Control_3Phase.bat'

- 1) Program control - hit 'PLAY' to start
- 2) Flags for App running, USB comms and Motor in place.
- 3) Frequency of output
- 4) RUN: needs pressing to turn outputs on
- 5) SINE / DIGITAL: Sine or Square wave output
- 6) 20V / 12V output: alters the output voltage
- 7) IMPROVED / STANDARD: alters output waveform quality
- 8) BRUSHLESS MODE: indicates Brushless motor is plugged in
- 9) Meters for the output - RMS values
- 10) Dynamometer load as a %
- 11) Dynamometer speed in RPM

- 12) Dynamometer power in watts
- 13) Torque in mNm
- 14) ZERO: Zeros the torque sensor
- 15) REAL/EFFECTIVE: adjusts the way the graph plots the output waveform.
- 16) PHASE / TIME: shows X axis in degrees or in mS
- 17) CAPTURE: captures a waveform.
- 18) Oscilloscope plot area
- 19) Internal ammeter and voltmeter V1 and I1
- 20) Properties

This application runs the three phase motor and the Brushless DC motor.

Three phase AC automatic



The file name for this program is 'Open Log_3Phase.bat'

- 1) Program control - hit 'PLAY' to start
- 2) Flags for App running, USB comms and Motor in place.
- 3) Frequency of output
- 4) RUN: needs pressing to start the program
- 5) SINE / DIGITAL: Sine or Square wave output
- 6) 20V / 12V output: alters the output voltage
- 7) IMPROVED / STANDARD: alters output wave-form quality
- 8) SWEEP: starts sweep function
- 9) BRUSHLESS MODE: indicates Brushless motor is plugged in
- 10) Meters for the output - RMS values
- 11) Dynamometer load as a %

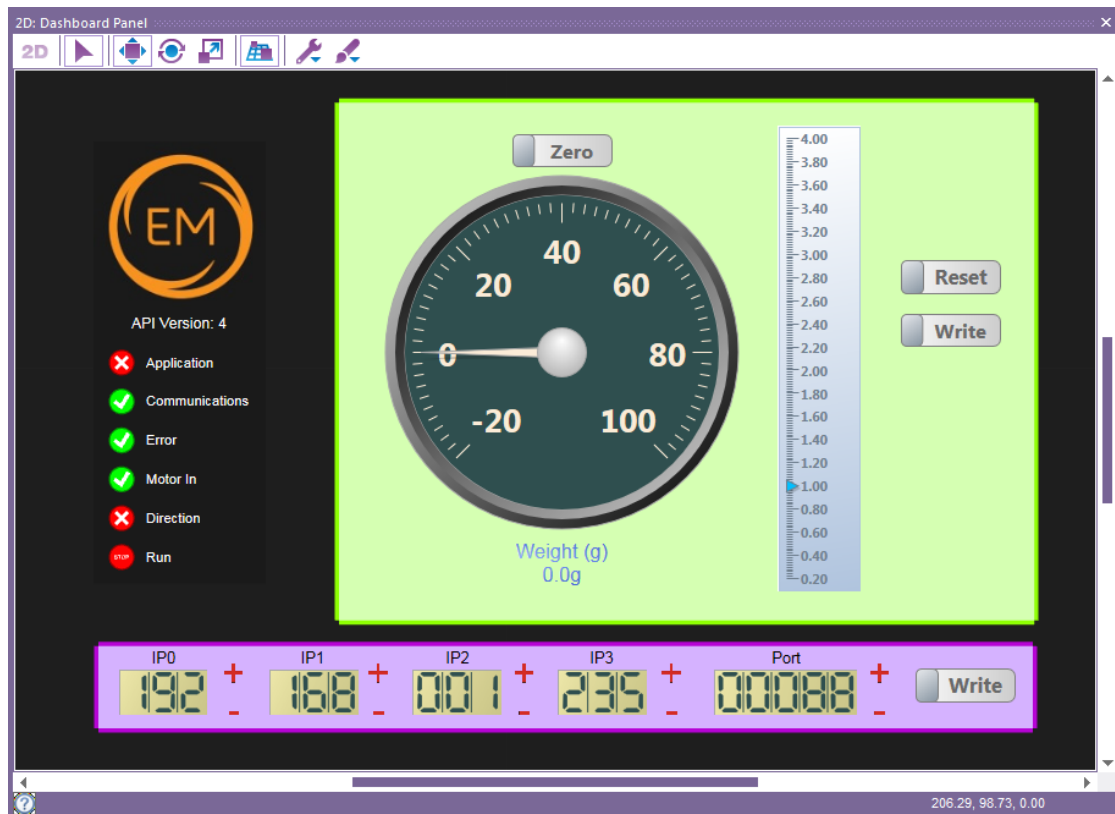
- 12) Dynamometer speed in RPM
- 13) Dynamometer power in watts
- 14) Torque in mNm
- 15) ZERO: Zeros the torque sensor
- 16) Graph / log clear button
- 17) On screen graph of plot data
- 18) Internal ammeter and voltmeter V1 and I1
- 19) Properties

This application runs the three phase motor and the Brushless DC motor.

When the SWEEP button is pressed the control box will - at the specified frequency output take readings from 0 load to 100% load in 2% increments. The results will be stored in the file LOG_3phase.CSV for plotting in Excel.

Up to 8 data sets can be captured and displayed at one time.

Calibration and IP set up



The file name for this program is 'Open Calibration.bat'. This software application has two functions: it allows you to calibrate the load cell and it allows you to set the IP address of the control unit.

Calibration

- 1) Connect the Dynamometer to the control unit with the 25 way D type.
- 2) Twist the dynamometer anti clockwise so that it is not pressing on the load cell at the back of the Dynamometer.
- 3) Press PLAY on the software App. Press RESET. Press Zero.
- 4) Place a 20 gram weight on the end of the load cell. Use the slider multiplier on the App to adjust the dial so that it reads 20g.
- 5) Click on the Write button to save the calibra-

tion into the control box.

- 6) Remove the weight. Press Zero. Your Control unit and Dynamometer are now calibrated together.

- 7) Check the calibration by putting the weight on and making sure the display reads 20g.

If you have multiple sets of Electrical Machines then make sure that they are paired for the next time you use them. This will have been performed for you in the factory so this should not need doing on starting.

IP set up

- 1) Press PLAY on the App
- 2) Use the '+' and '-' buttons on the IP number fields to set the IP address you want
- 3) Click on the WRITE button to save this IP address to the Control box.

Remote Lab Connection

This document outlines the process users should follow to remotely connect an electrical machines control box to a network or internet to allow remote control. This can only be actioned on units purchased since June 2020.

Accessing using local network

The default IP address of the Electrical Machines box is 192.168.1.235 and the default port is 88. The IP address and Port can be changed by connecting to the box using a USB connection and running the calibration application. The Ethernet connection must be connected to the network and then the IP address and Port can be used in the software applications to connect to the Electrical Machines box.

Accessing using the Internet

Before accessing the Electrical Machines box from the internet make sure the box is functioning correctly on the local network. This helps to pin point any connection problems down to the IP and Port of the box or the configuration of the router.

To access the Electrical Machines box from the Internet the user must ensure they have enabled port forwarding on their own router, (the connection from your local network to the internet). This takes incoming connections from the internet and routes them to the correct internal IP address. Use the routers IP address in the software applications.

Information on enabling Port Forwarding on your router: <https://portforward.com/>

Information on finding your routers IP address. <https://whatismyipaddress.com/>

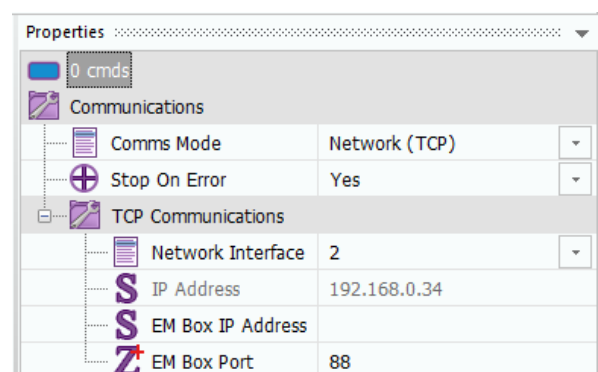
On a home routers (for example in the students' or lecturers home) you may also need to enable a demilitarised zone (DMZ) to the Electrical Machine box IP address to allow incoming Internet traffic to reach it. A commercial router may not have to do this.

Configuring the software application

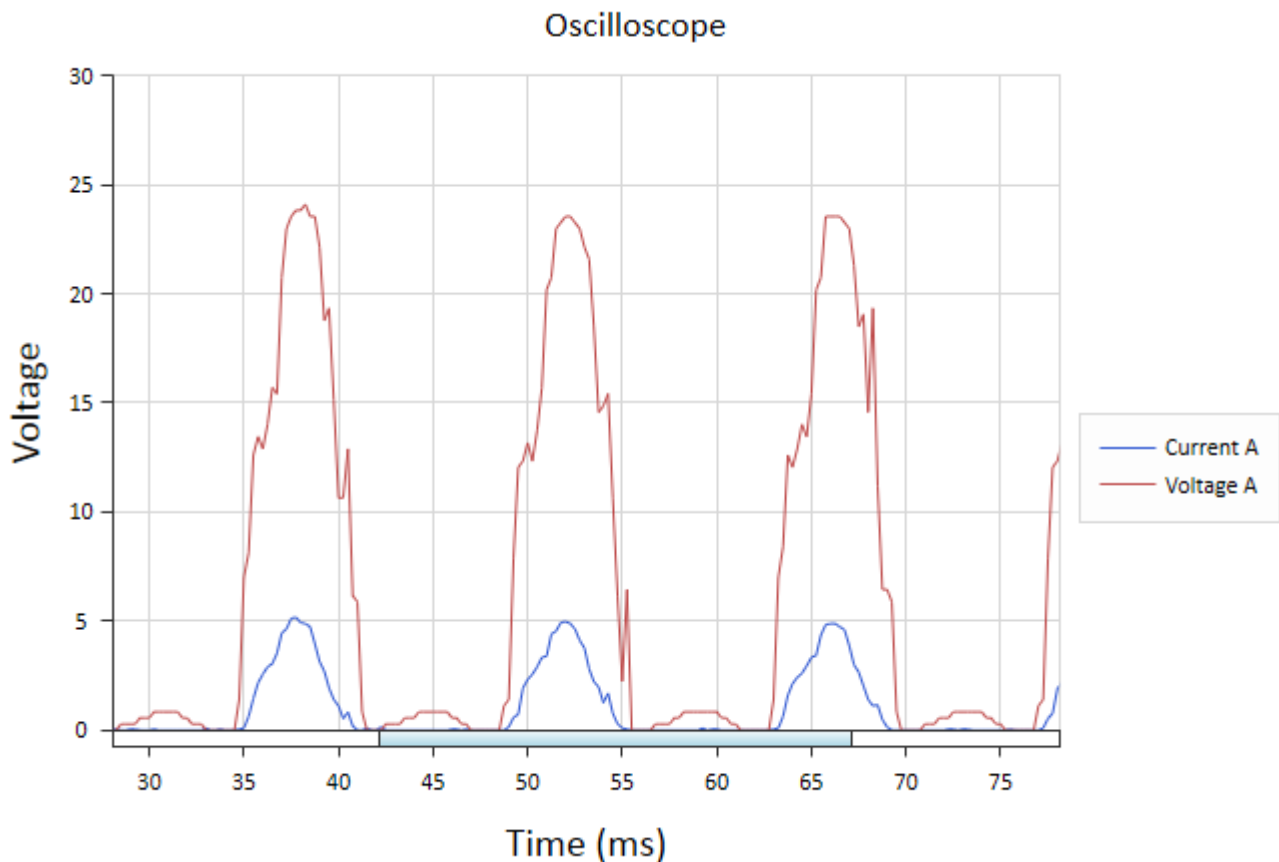
Using the software application downloadable from the Matrix website: www.matrixtsl.com/electrical-machines/resources/, the user starts the Electrical Machines software application for the specific machine they have in test.

Ensure Network (TCP) communications is selected (not USB). Under the TCP communications menu, select the network interface that provides a sensible IP value. In the EM box IP address, enter the IP for your control box. In the EM box Port, enter the Port number for your control box.

NB: Matrix TSL are unable to provide help in configuring the IP systems of third parties because of the complexities inherent in this. Local area network managers should be able to provide this support.



The on- board oscilloscope



The oscilloscope in the Control unit takes measurements of every ammeter and voltmeter in the unit at a rate of 64kHz. There are 16 channels in total - that gives us an effective measurement rate of 4kHz for each channel.

Y axis, Timebase and traces can be set by clicking on the appropriate words in the Properties section at the right hand side of each application.

To alter the time base: click on the oscilloscope area and use the mouse wheel to zoom in and out.

The oscilloscope is useful for seeing voltages and currents at close to the driving frequencies. In fact we use a small capacitor on the input to deliberately slow the effective rate of sampling to make the instrument work better for this

purpose.

Because the PWM frequency used is 7kHz and the effective sampling rate is 4kHz then Nyquist effects can be seen when zooming in to examine the PWM drive frequency. Because of this an external oscilloscope needs to be used when examining waveform structure in detail.

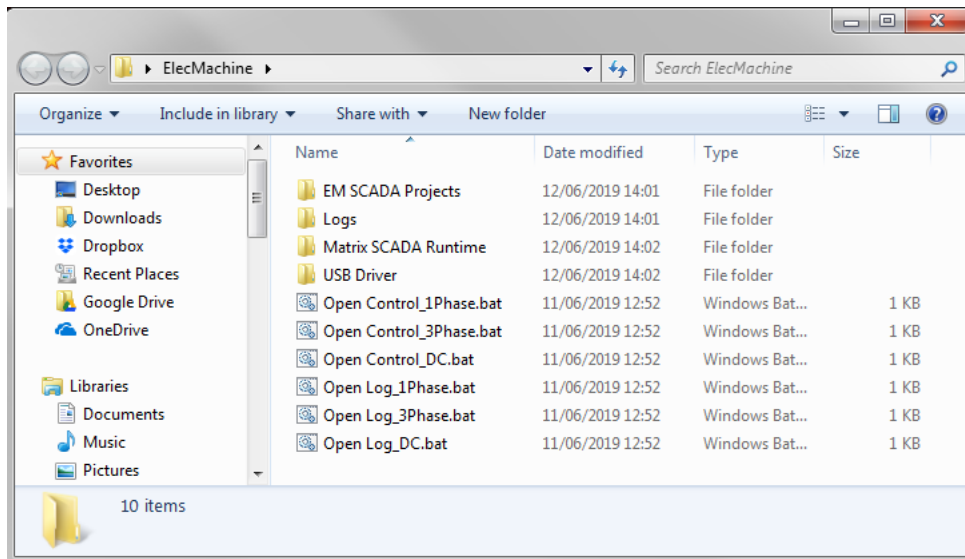
The oscilloscope is particularly good at showing currents the pattern of voltage and current and the phases between voltage and current.

The oscilloscope in the three phase programs has the ability to show Real voltage or Effective voltage as standard. Users at this level should always use Effective voltage.

Software installation

Copying over the software

The software for Electrical Machines is available as a download from the Matrix web site. When you unpack the zip file you will see the following files:



There are 6 applications that are used for the Electrical Machines range. These are documented below.

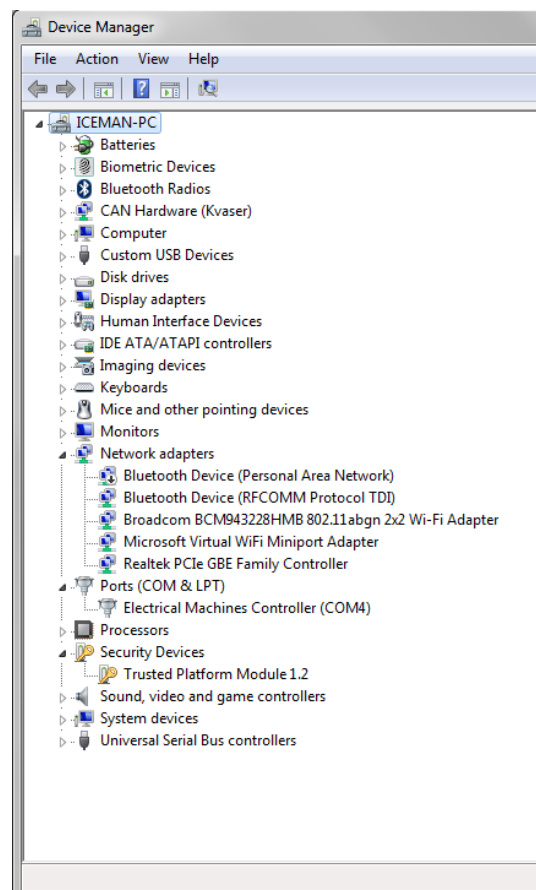
Please copy these programs and directories into a suitable location on your hard drive. You can make short cuts to the *.BAT files if you wish.

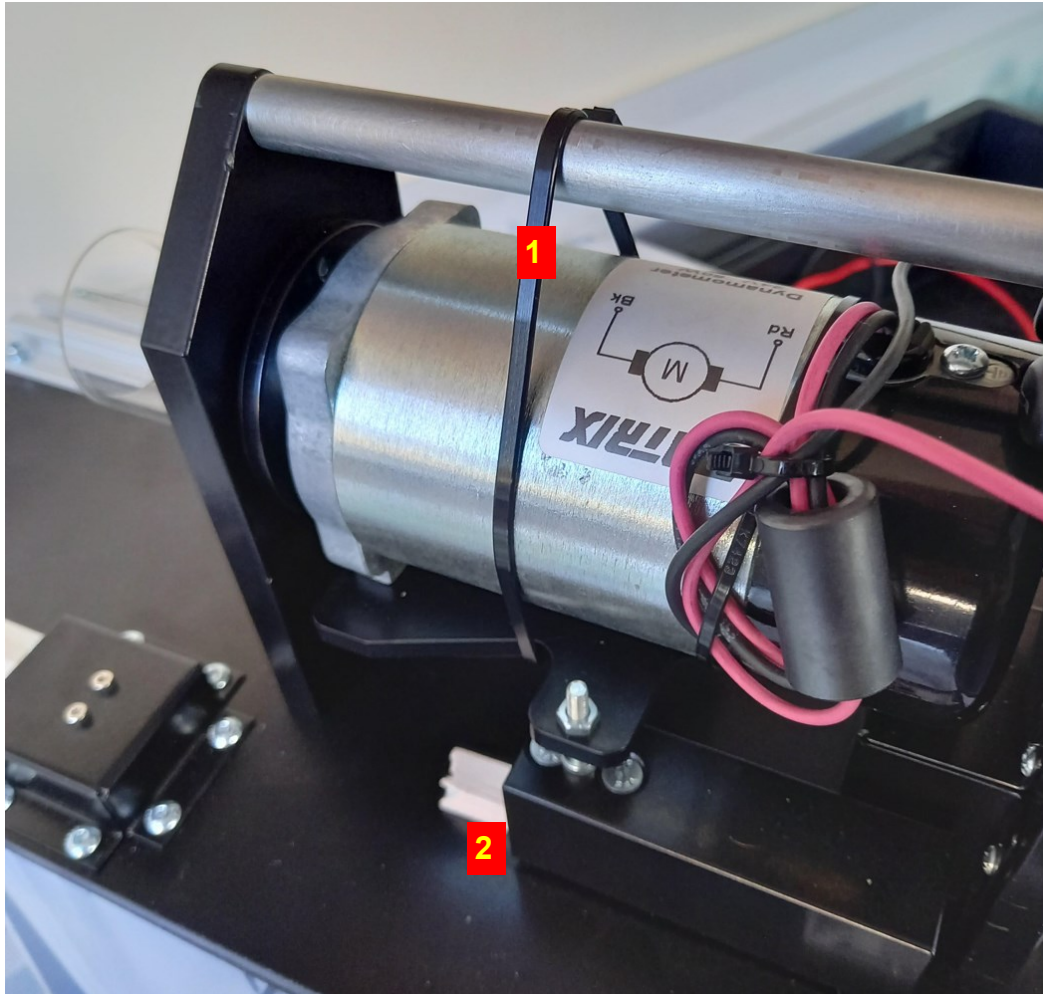
Run each program by clicking on the '*.BAT' file.

Installing drivers

Go into the USB drivers folder and run the 32 bit or 64 bit as appropriate for your computer. This should install the driver for the control box.

You can check the driver is installed properly by looking at Device Manager and checking that the Electrical Machines controller appears under Ports - see opposite.





Packaging may vary from one batch to another. To prevent the mechanism of the Dynamometer from damaging itself or losing calibration during shipping the Dynamometer body and load cell are protected from each other. Please refer to the photograph above.

- 1) To protect the product in shipping a cable tie is strapped round the Dynamometer body to prevent it moving and damaging the mechanism. This should be cut with a pair of wire cutters to allow the Dynamometer to rotate.
- 2) To protect the sensor a block of wood is fitted under the load cell sensor. This can be removed manually.