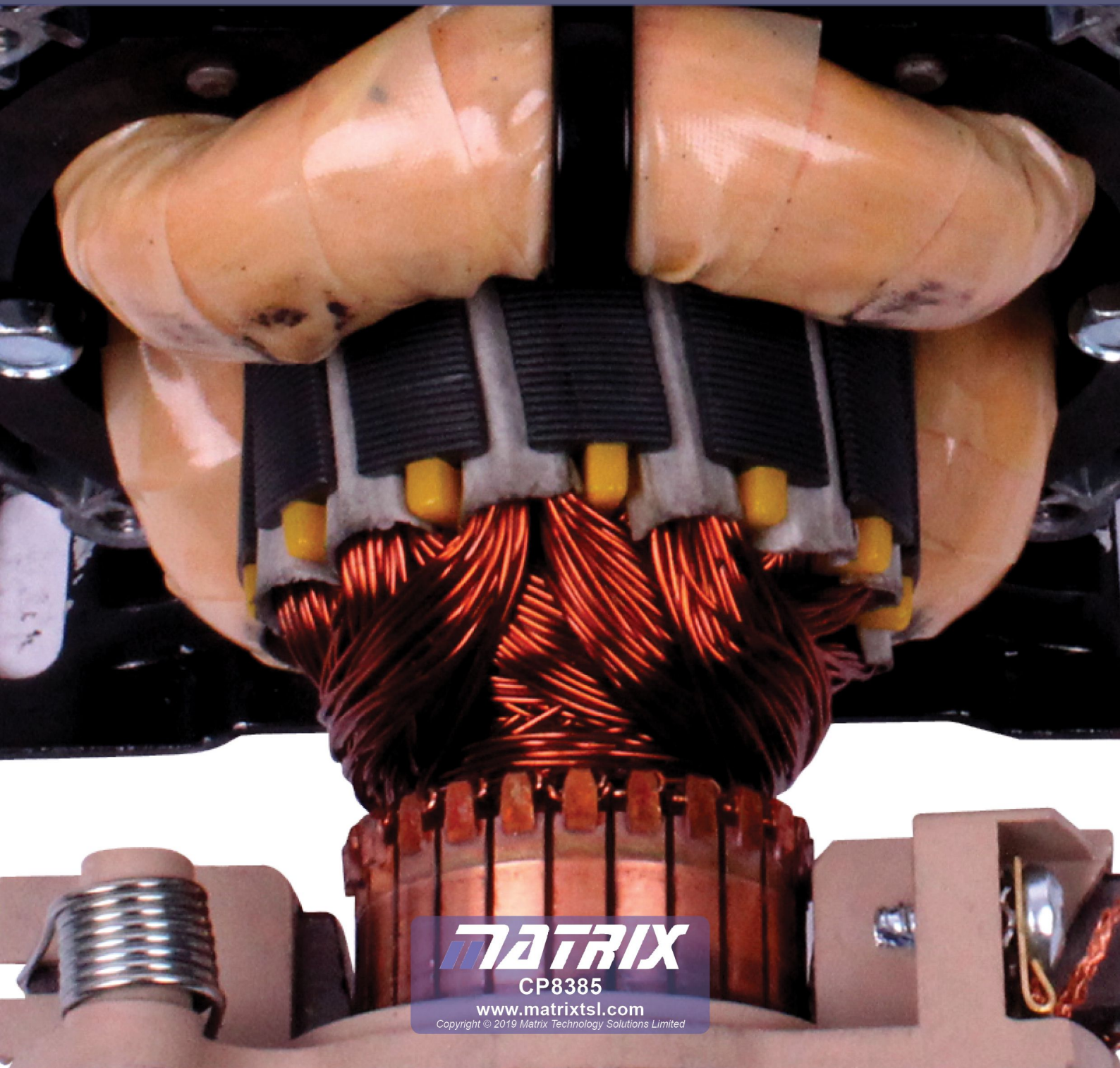
EM ELECTRICAL MACHINES

Electrical machines & MATLAB control



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Contents

Electrical machines and MATLAB

Health and safety

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.

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.

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.

Please:

Should an accident happen while the equipment is being used, please report it to us, at the address below, so that we can consider how to make the equipment even safer.

Design team

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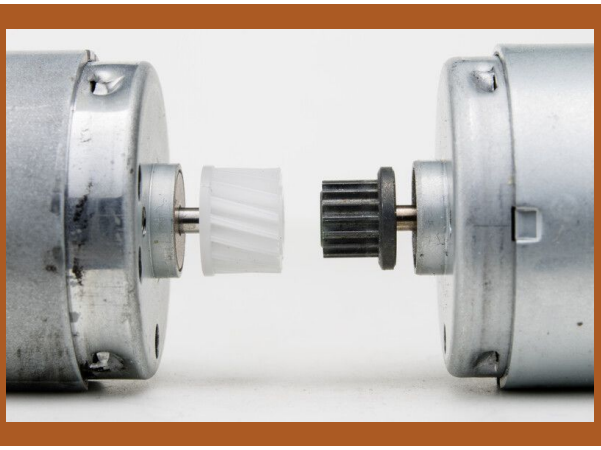
Worksheets

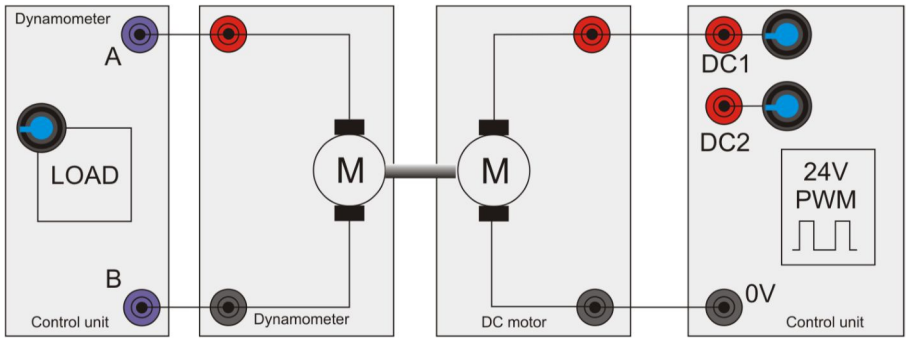
Worksheet 1
Getting started

Electrical machines and MATLAB



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.

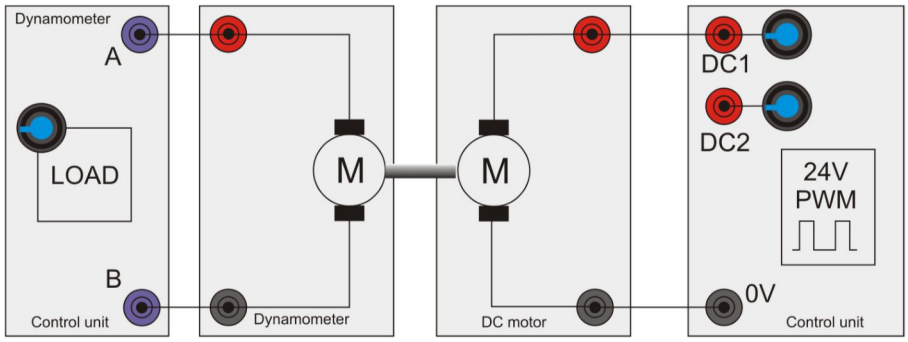


1) Set up the DC motor and dynamometer as shown in the diagram above.
2) Make sure that the unit is working properly: disconnect the USB lead and use the manual controls to operate the DC1 output voltage to vary motor speed. Make sure that it turns clockwise and puts pressure on the load cell. Make sure that the dynamometer is connected properly and that increasing the dynamometer load slows the motor down.
3) Make sure that you have the drivers for the control unit installed on your computer. If not follow the instructions in the MATLAB software reference section below.
4) Reconnect the USB lead.
5) Refer to the MATLAB Software reference section at the back of this document to understand the MATLAB functions available to you.
6) Create a simple MATLAB program that controls the speed of the DC motor.
7) Extend your program to allow you to control the Dynamometer load.

Worksheet 2
Using MATLAB for graphing

Electrical machines and MATLAB

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.



With the same set up as the previous work-sheet:

1) Create a program that runs the DC motor at 50% of its max output power.
2) Modify the program so that it increases the Dynamometer load from 0% to 100% in 4% steps.
3) Create routines that measure the torque on the load cell.
4) Create routines that measure the speed of the motor in Revolutions Per Minute (RPM)
5) Plot the RPM against torque to a graph. This is a speed-torque curve for the DC motor. Speed torque curves are the most basic way of characterising electrical machines.
6) Create additional routines that make plots for speed vs current, and torque vs current.

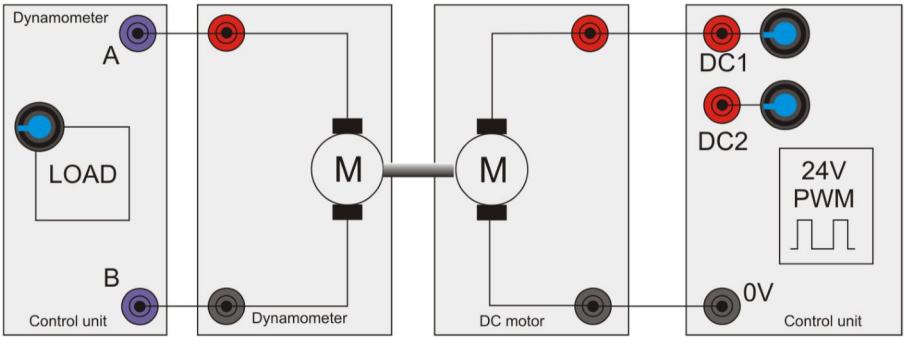
Worksheet 3
Closed loop control

Electrical machines and MATLAB

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.

For dodgems speed control is usually simple on-off.



In an industrial context you will often need a motor to be running at a constant speed. Independent of the load that is put on it. Using the same set up as before:

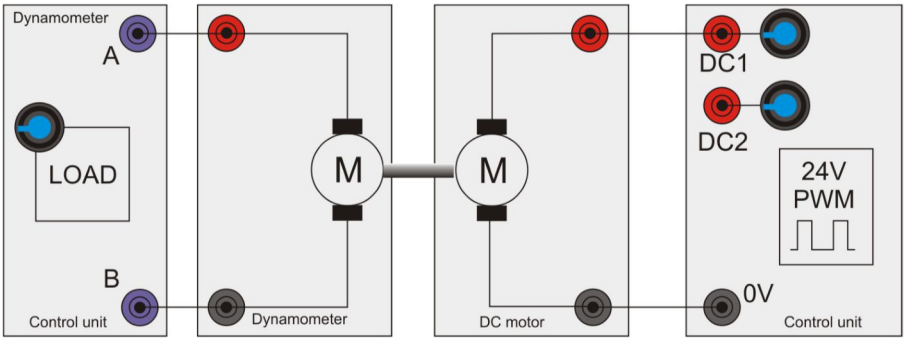
1) Create a closed loop system script to run the motor at a defined speed.
2) Vary the load to the motor using the SetDynoLoad API function and confirm that the speed remains consistent.
3) Can the speed be made consistent for all values of load?

Worksheet 4
Speed control strategies

Electrical machines and MATLAB

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.



A motor cannot go from not moving to moving at a certain speed in an instant. The techniques of getting from zero speed to rated speed have many implications in designing motor control systems.

1) Create a script to allow the motor speed to be ramped up and ramped down to achieve the desired speed and reduce excess current usage.
2) Investigate the use of Proportional, Integral and Derivative measurements (PID) for controlling the speed of motors.
3) Create a variation on your graph routine that allows you to plot the motor speed for a certain time during starting a motor.
4) Use PID techniques to create a program in MATLAB that optimally ramps the speed of the system from standstill to 1500RPM without going over this speed.
5) Modify your program so that it allows the dynamometer to vary the load within 0% of load and 70% of load and yet still maintain the rated speed of 1500 RPM.
6) Use the plots from y our graph to prove the system performance is within specification.

Package information

Reference
Understanding the system

Electrical machines and MATLAB

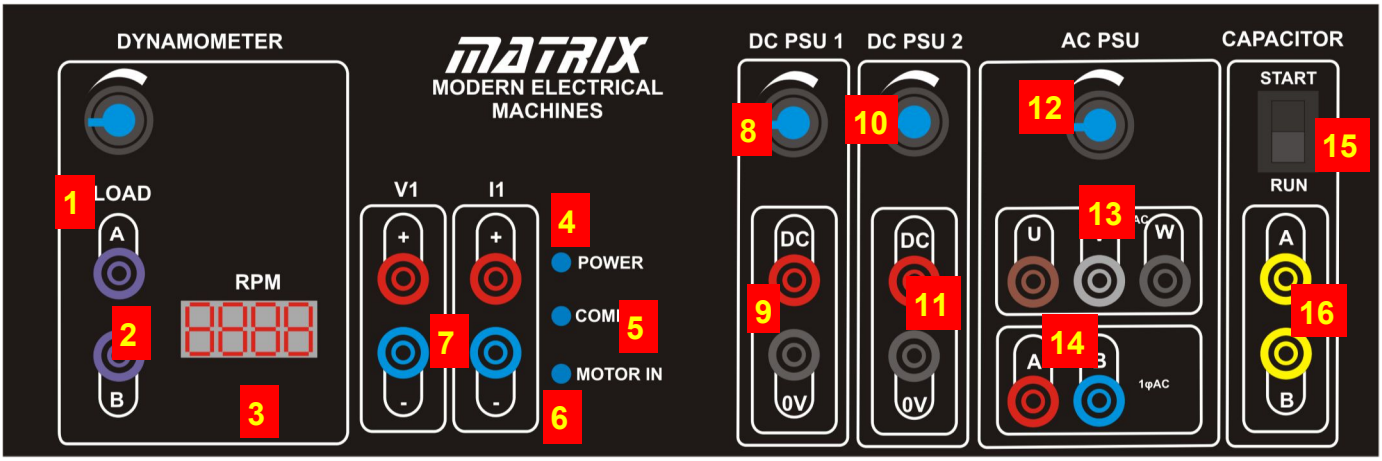
The system consists of a number of 24V electrical machines, a control unit, software applications for driving the control unit and a set of worksheets. The photograph above shows these parts. They are:

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

Reference
Understanding the control unit

Electrical machines and MATLAB

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

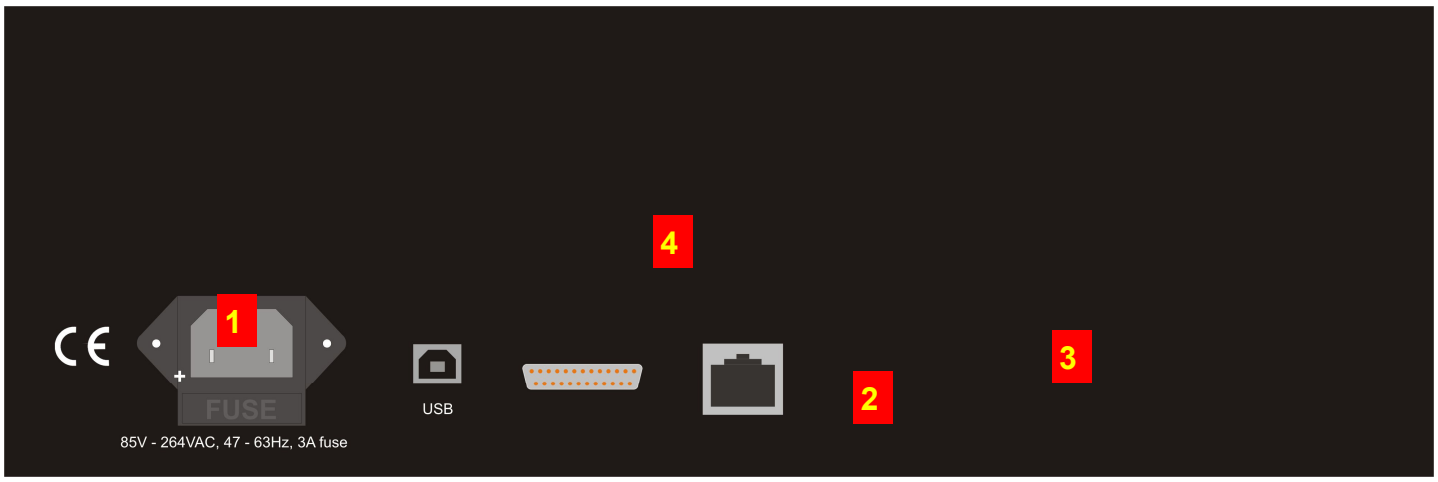


1) The dynamometer resistance: use this to control the effective resistance placed across the dynamometer: low electrical resistance means a large mechanical resistance, and high electrical resistance means low mechanical resistance
2) The dynamometer connections
3) The speed of the motor in Revolutions 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.

Reference

Understanding the control unit

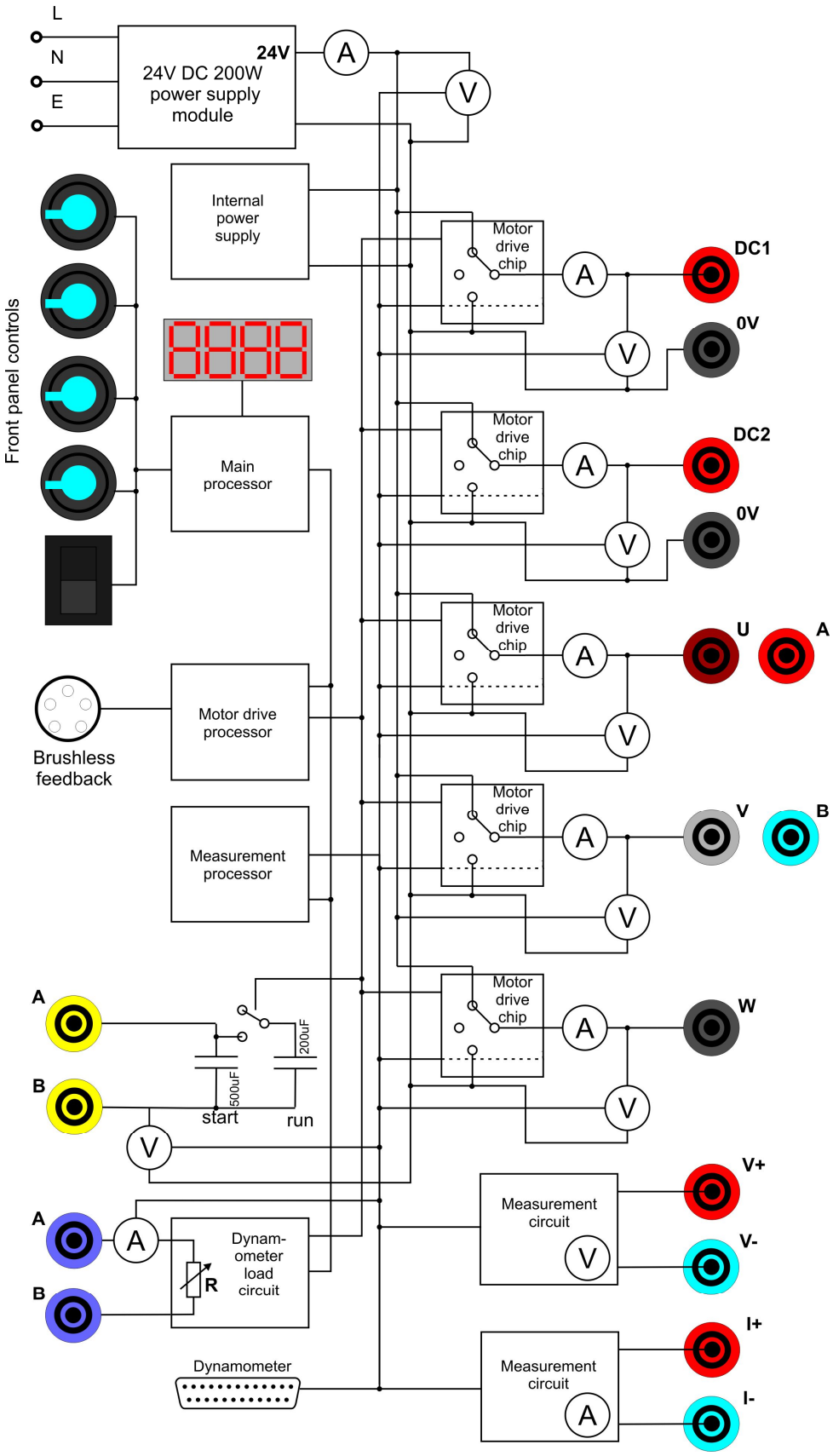
Electrical machines and MATLAB



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 Dyna-mometer
4) Vent holes for internal fan - do not cover.

Reference

Control unit schematic



Reference

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 around 13 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 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.

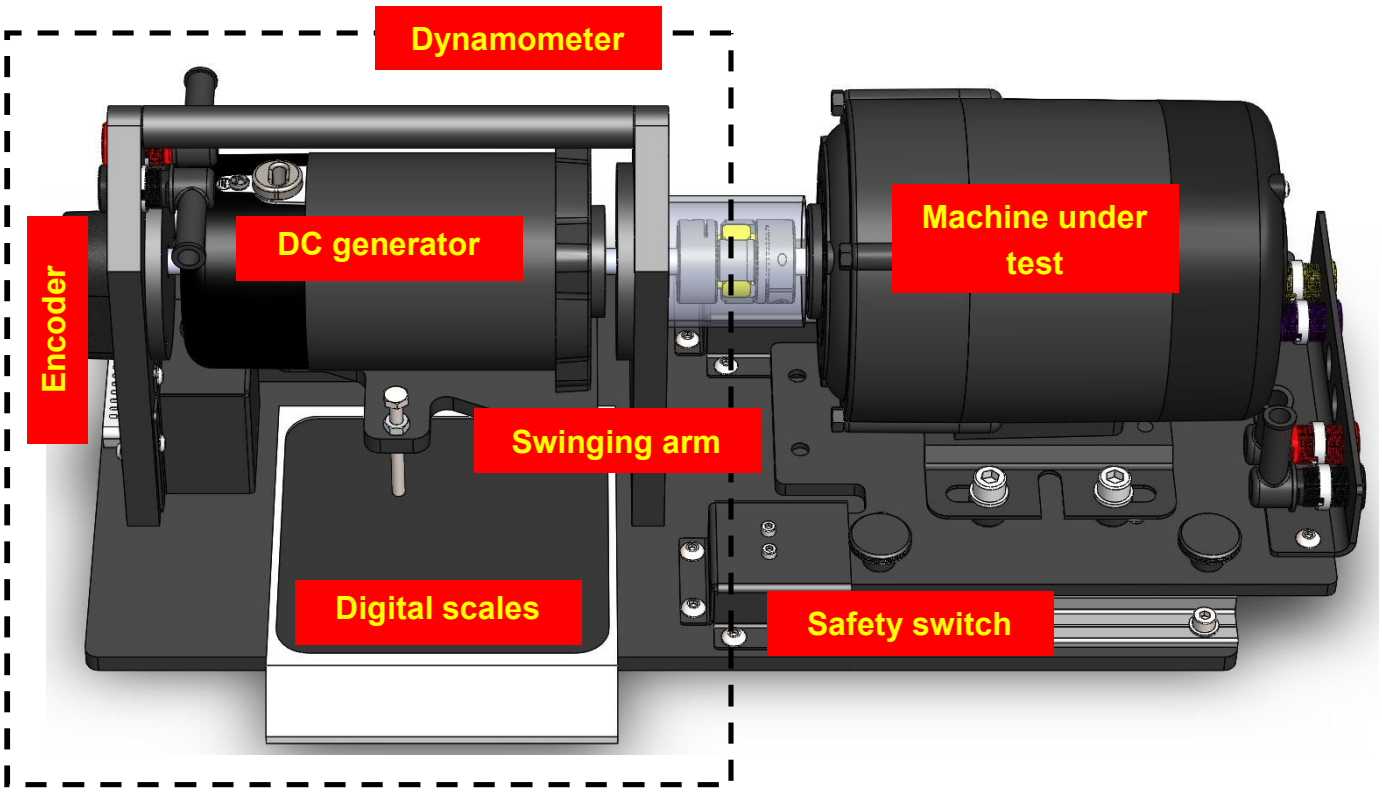
The motor driver chip outputs can be placed in one of three states: 24V, 0V and open circuit. This allows for different drive strategies when generating waveforms for driving motors. As part of the learning package students investigate PWM for driving DC motors, and Pseudo-sine waves for driving single 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.

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.

Reference

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:

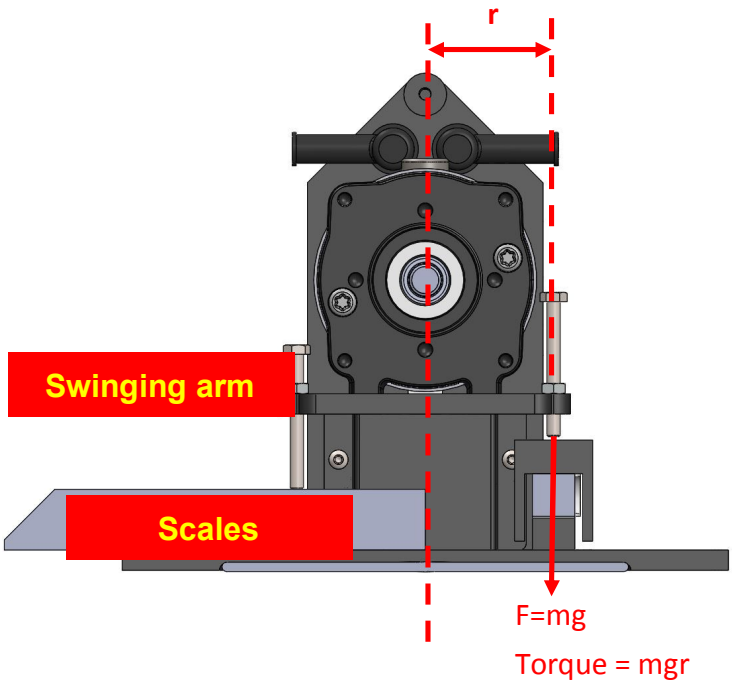
- A digital scale (shown in the image above) can be used to measure the effective vertical force on the scale and it gives a reading in Kilograms. This can be converted into newtons and newton metres - see below.
- A load cell (behind the dynamometer and not shown in the image above) connected to the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

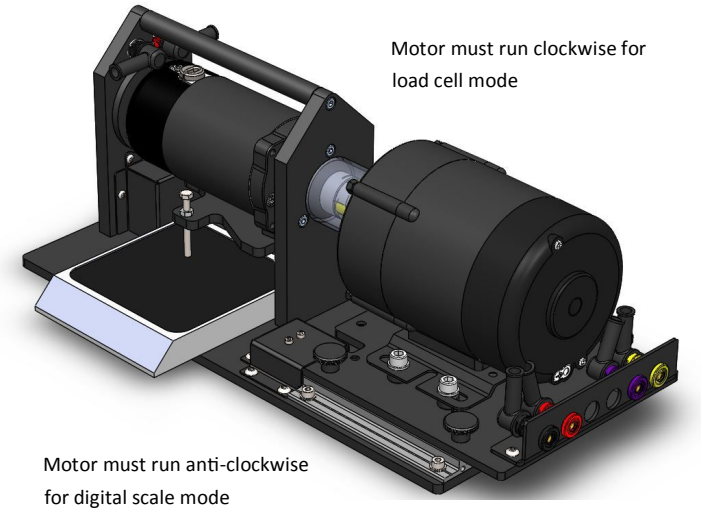
Note that the rotation of the dynamometer dictates whether the balance or the load cell is used. Controlling the direction of motion of each machine is discussed below.

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 anticlockwise) 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 Force = mass x 9.81m/s^2. The torque can be calculated from the formula Torque = Force x 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 = 38.12mm**

More discussion on calculations is given below.

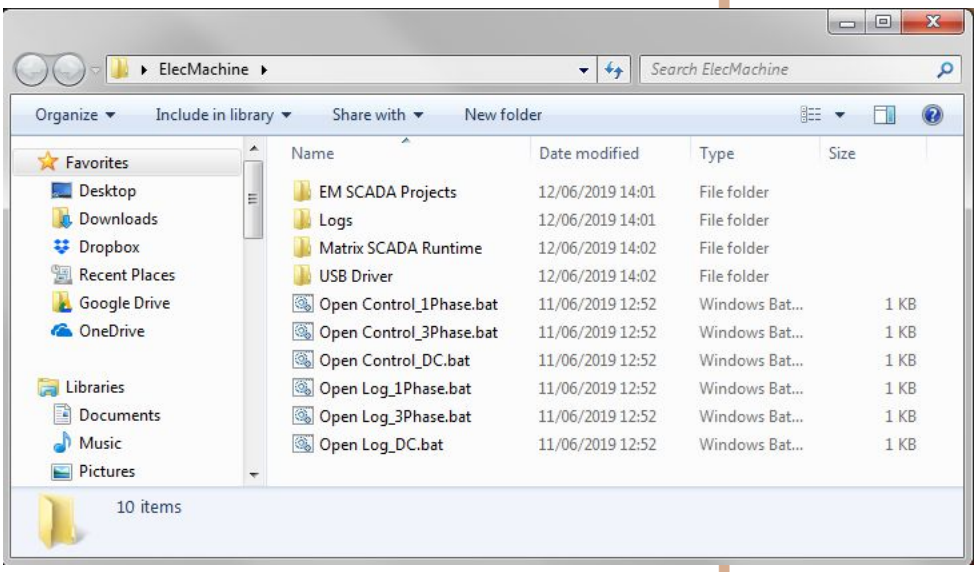
Software Information and MATLAB API

Reference
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.



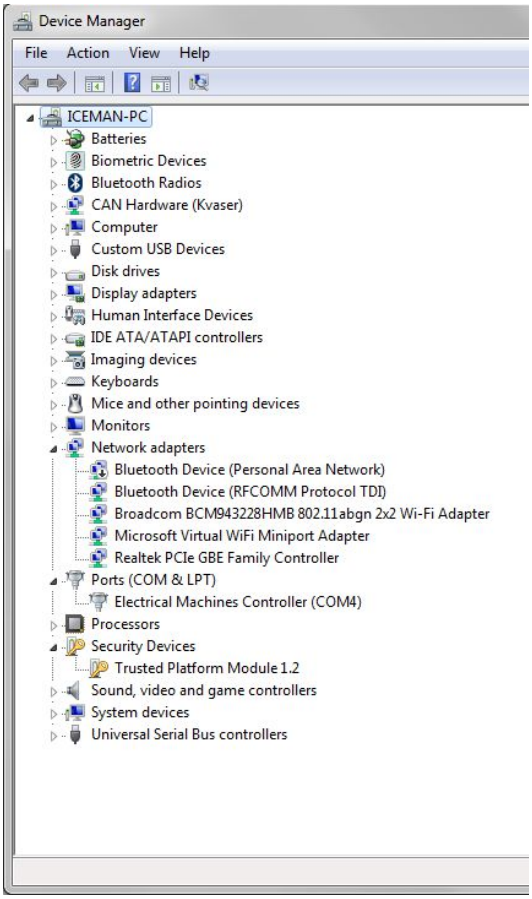
Please copy these programs and directories into a suitable location on your hard drive. You can make short cuts to the *.BAT files if you wish.

Rin 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 y our 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.



Reference
Software: MATLAB integration

Electrical machines and MATLAB

The MATLAB software is available as a download from the Matrix web site.

The Modern Electrical Machines functionality is controlled via a USB COM port connection to the computer.

We have provided a library of functions to allow the various aspects of the Electrical Machines system to be investigated and controlled. The various Machines function scripts can be found inside the Primitives folder. The scripts require a global variable to be declared in your project to set the COM port number as shown opposite:

```
global EM_USB;
% Find the COM port on your PC where the Matrix
EM control unit is plugged
% in and use it here instead of 'COM1'
EM_USB = serial
('COM1','Baudrate',115200,'Databits',8);
fopen(EM_USB);
% Main program resides here
fclose(EM_USB) % Close the COM port
```

Reference
MATLAB functions

Comp Code	Cmd Code	Function	Param1	Param2	Param3	Param4	Return	Return Size	Description
0	0	GetAPIVersion					VersionNumber	Byte	Gets firmware API version - Should be set to 1 on release
0	1	SetMotorType	Type (0-3)						Sets the motor drive type - 0=DC, 1=1 Phase, 2=3 Phase, 3=PIDControl
0	2	SetVoltage	VoltageLSB	VoltageMSB	Channel (0-1)				Sets the voltage of one of the DC outputs (0-3000)
0	3	SetFrequency	FreqLSB	FreqMSB					Sets the AC drive frequency (10 - 100)
0	4	SetActive	Run (0-1)						Controls if the outputs are live or not
0	5	SetPhase	Channel (0-2)	PhaseLSB	PhaseMSB				Allows one of the AC phases to be shifted from the default 180 or 120
0	6	ZeroWeight							Zeros the output of the load cell
0	7	SetACDriveMode	Mode (0-1)						Sets the AC output waveform mode 0=Sine Wave PWM 1=Trapezoidal
0	8	SetFanSpeed	SpeedLSB	SpeedMSB					Controls the fan speed, largely redundant now and fan should be automatic (0-3000)
0	10	SetCapBank	Value (0-3)						Controls the capacitors connected to the C terminals - 0=OF, 1=200uF, 2=300uF, 3=500uF
0	11	SetDynoLoad	Value (0-255)						Controls the dynomometer load resistance (0=approx 145R, 255=approx 5R)
0	12	SetACGenMode	Value (0-1)						Controls the Three phase sine wave generation (0=Simple, 1=Accurate (double hump))
0	13	GetLogData						Byte[64]	Collects a 64-byte packet containing log data
0	14	LogDataReady					Ready (0-1)	Byte	Checks to see if the log data is ready to send
0	15	IsBrushlessActive					Active (0-1)	Byte	Checks to see if the brushless feedback is connected
0	16	GetLogStartAngle					Angle(0-35)	Byte	Gets the Current U phase angle at the start of the log, 0-35 = 0 to 350 degrees
0	17	Load Cell Calibration	FloatLSB	Float1	Float2	FloatMSB			Sets the load cell scaling factor - usually 0.004608294930875
0	20	GetRPM					RPM	Unsigned Int	Returns RPM reading with resolution of 0.1 RPM
0	21	GetAbsolutePosition					AbsPosition	Unsigned Long	Returns the absolute encoder position with resolution of 0.25 Degrees
0	22	GetVoltage	Channel (0-5)				Voltage	Unsigned Int	Returns Voltage reading with resolution of xxx V
0	23	GetCurrent	Channel (0-7)				Current	Unsigned Int	Returns Current reading with resolution of xxx V
0	24	GetErrorStatus					ErrorStatus	Byte	Gets the current error status
0	25	GetSwitches					Switch	Byte	Returns the state of the saftey switches (0=Stop, 1=OK)
0	26	GetLoadCell	Mode (0-1)				Load	Unsigned Int	Returns the weight on the load cell 0=Weight in G 1=Torque in mNM
0	27	GetPhaseAngle	Channel						Returns the phase angle difference measured using peaks in the waveform
0	28	GetMotorDir					Direction	Byte	Returns the direction the motor is turning
0	29	ResetAbsPosition							Resets the absolute angular position to 0
0	50	SetSetpoint	FloatLSB	Float1	Float2	FloatMSB			Sets the angle setpoint
0	51	SetKP	FloatLSB	Float1	Float2	FloatMSB			Sets the proportional gain
0	52	SetKI	FloatLSB	Float1	Float2	FloatMSB			Sets the integral gain
0	53	SetKD	FloatLSB	Float1	Float2	FloatMSB			Sets the derivative gain
0	54	GetFeedback					Angle	Float	Gets the absolute position as a floating point angle
0	55	GetControlOutputs					OP,OI,OD,Sum	Float[4]	Gets the PID control outputs as floating point values
0	56	SetMaxDriveDuty	FloatLSB	Float1	Float2	FloatMSB			Sets the max drive duty as a floating point value between 0 and 1.
0	57	GetDataArraySize					Number of sampl	Byte	Collect number of control samples in the buffer
0	58	GetDataArray						Float[5]	Collect SP, FB, PO, IO, DO
0	59	Get3xDataArray						Float[15]	Collect Data Array x 3
0	80	SetIPAddress	IP0	IP1	IP2	IP3			Sets the IP Address of the box, default 192.168.1.235
0	81	SetIPPort	PortLSB	PortMSB					Sets the Port for the box, default 88

The table above shows the public function calls that are available in the MATLAB library and their function.

Reference
MATLAB example

The text opposite is a simple motor control script written in Matlab. This and the sets of API commands on previous pages should help you to create your Electrical Machines test programs.

```
global EM_USB;
% Replace 'COM1' with correct port number for EM box
EM_USB = serial('COM1','Baudrate',115200,'Databits',8);
fopen(EM_USB);
SetMotorType (0);    % DC Motor
pause(0.1);
motor_voltage = 10;   % 10V DC

% Test comms are ok
api_version = GetAPIVersion();
disp(['api_version = ' , num2str(api_version)]);

% Check the dyno safety switches
switch_state = GetSwitches ();
if switch_state >= 1
  disp('==== DC MOTOR TEST START ====')
  SetDynoLoad(0);
  index = 1;
  SetActive(1); % Motor ON
  SetVoltage(0,motor_voltage); % Set Voltage DC1
  pause(0.3); % Wait for the motor to spin up
  % Perform the sampled measurements in a loop
  for loop = 0:255
    load_cell_torque_range(index) = GetLoadCell(1);
    encoder_speed_range(index) = GetRPM();
    index = index + 1;
    SetDynoLoad(loop);
    pause(0.1);
  end
  % Sampling over, turn off the motor, close comms
  SetActive(0); % Motor OFF
  fclose(EM_USB)

  % Plot the RPM against Time
  curent_torque_plot = figure;
  figure(curent_torque_plot);
  movegui(curent_torque_plot , 'northwest');
  hold on
  p2 = polyfit(encoder_speed_range, load_cell_torque_range , 1); %
line of best fit
  y2 = polyval(p2, encoder_speed_range);
  plot(encoder_speed_range, load_cell_torque_range, 'ro', encod-
er_speed_range, y2, '-r' );
  current_speed_polynomial = poly2sym(p2,sym('T'));
  current_speed_equation = sprintf('Speed = %
s',current_speed_polynomial);
  disp(current_speed_equation);
  grid on
  legend('Samples','Best fit line','Location','southeast');
  xlabel('Speed, RPM');
  ylabel('Torque, mNm');
  title(['PM DC Motor Speed v Torque @ ', num2str(motor_voltage) ,
'V']);
  hold off
else
  disp('==== Motor not fitted in Dynomometer ====');
end
```

Instructor Guide

Instructor Guide

Electrical machines and MATLAB

About this course

Introduction

The Electrical Machines and Matlab course is designed to both improve your Matlab skills and gain familiarity with controlling modern electrical machines. The course covers basic motor operation through to advanced closed loop control and beyond. The electrical machine equipment allows the exploration of various types of motor without any risk of electrical shock or mechanical entanglement. The electrical machine control box exposes it's functionality via a command API that is accessible via the USB connection. Matlab can tap into this API to allow the various features of the motor controller box to be controlled alongside Matlab's powerful mathematic engine.

Aim

The aim of the course is to teach the operation of motors, theory behind the motor drive electronics as well as high level means of control using Matlab. Matlab then provides a series of tools which can be used to take things further in terms of modelling the motor and increasing efficiency in existing machinery.

Prior Knowledge

It is recommended that student have prior knowledge in using Matlab, writing Matlab .m script files and using Matlab to create chart plots. They should also have a basic understanding of the motors they are controlling as well as how they are driven.

About these worksheets

It is expected that the series of experiments given in this course is integrated with teaching or small group tutorials which introduce the theory behind the practical work, and reinforce it with written examples, assignments and calculations. The worksheets should be printed / photocopied / laminated, preferably in colour, for the students' use. Students should be encouraged to make their own notes, and copy the results tables and sections marked 'For your records' for themselves. They are unlikely to need their own permanent copy of each worksheet.

It is for the instructor to monitor that students' understanding is keeping pace with their progress through the worksheets. One way to do this is to 'sign off' each worksheet, as a student completes it, and in the process have a brief chat with the student to assess grasp of the ideas involved in the exercises it contains.

Time:

It will take students between 10 and 20 hours to complete the worksheets.

It is expected that a similar length of time will be needed to support the learning that takes place as a result.

Instructor Guide

Electrical machines and MATLAB

Learning Objectives

On successful completion of this course the pupil will have learned.

- How to connect and communicate via a COM port using Matlab
- Refer to existing .m script files as subroutines and call them in their programs
- Run and Control the various types of motor using the EM hardware
- Characterise a motor by taking a sweep of readings
- Generate a best fit line for a motor
- Create an open loop control system to control the speed of a motor
- Create a closed loop control system to more accurately control the speed of a motor
- Understand the difference between stable and unstable systems

Equipment checklist

Electrical machines and MATLAB

To deliver this set of worksheets you will need:

Code	Description	Qty
COM7414	RS232 lead	1
EM1100	Red 100cm lead	3
EM1125	Black 100cm lead	3
EM1150	Green 100cm Lead	2
EM1175	Yellow 100cm lead	2
EM1190	Blue 100cm lead	2
EM2159	Dyno	1
EM2391	3 phase motor	1
EM5337	Brushless motor	1
EM6066	Control box	1
EM6574	DC motor assembly	1
EM7432	Series motor	1
EM8614	Single phase motor	1
EM9856	Shunt motor	1
HP2045	Shallow tray	2
HP3701	Mains lead	1
HP3844	Foam	5
HP4039	Lids	6
HP5540	Deep tray	3
HP6002	Cable for brushless motor	1
HP6529	Binding post	2
HP6640	Extra deep tray	1
HPUSB	USB lead	1
LK2346	Bulb	3
LK5203	10Kohm resistor	3
LK5243	Diode 1A	3
LK5250	link	5
LK5291	Lampholder	3
LK5297	Lead - black 4mm to 4mm unshrouded	1
LK5298	Lead - red 4mm to 4mm unshrouded	3
LK8900	baseboard	1
	Locktronics foam insert	1

If you intend to use an external meter, please note that it needs to be a true RMS meter. These are available from Matrix under product code HP1324 and two-per-set are required.

It is also recommended that for waveform generation, the use of a digital oscilloscope is necessary. These are available from Matrix under product code HP8067.

Troubleshooting

Dynamometer arm sticking

Problem: On newer models the Dynamometer arm can stick in the powder coating of the load cell. This affects readings at low torque.
Remedy: put a little WD40 on the load cell so that the arm does not stick

Problem: comms errors.
Solution: some lap tops seem to reduce the USB response speed as a battery saving measure .In Task manager set the SCADA app as a higher priority.

Version control

16 08 19 first release

02 07 20 Updated diagram for V1.1 control unit
Updated Matlab API list of functions
Updated block diagram