# THE UNIVERSITY OF NOTTINGHAM

## Department of Electrical and Electronic Engineering

## Power Electronics for Motor Control Project – H62EDQ

## Technical Supplement

## 1 BACKGROUND

Digital signal processors together with external hardware and appropriate software are used extensively for industrial control: a particular example is their use for motor control, an area of rapid growth and importance.

This project takes the simplest form of electronically controlled motor, the switched reluctance (SR) motor, as the target for some innovative electronic controls. The SR motor, Figure 1, works by magnetic attraction of a salient-pole rotor as it approaches salient stator poles momentarily energised for the purpose. The art is to energise the stator winding at the optimum instant (angle $\phi_0$) and for the optimum duration (angle $\phi_1$ - $\phi_0$) (sometime called dwell angle) so that the attractive forces are maximised to produce maximum torque. These angles, however, depend on motor speed. See figure 2 for an example. Torque control can also be achieved via direct control of the motor current.

A measurement of rotor angle ($\phi$), shown in figure 1, is clearly essential so that the switching of current to the motor winding can be optimally timed directly (or indirectly) from rotor angle.

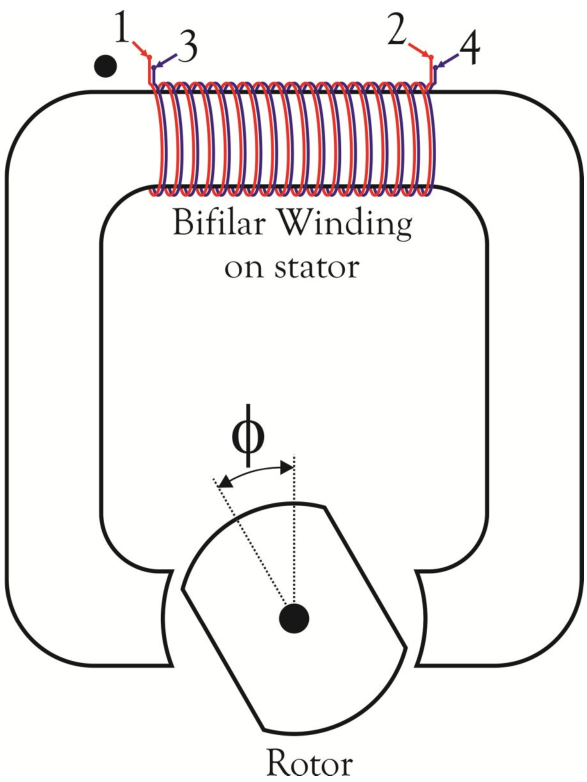
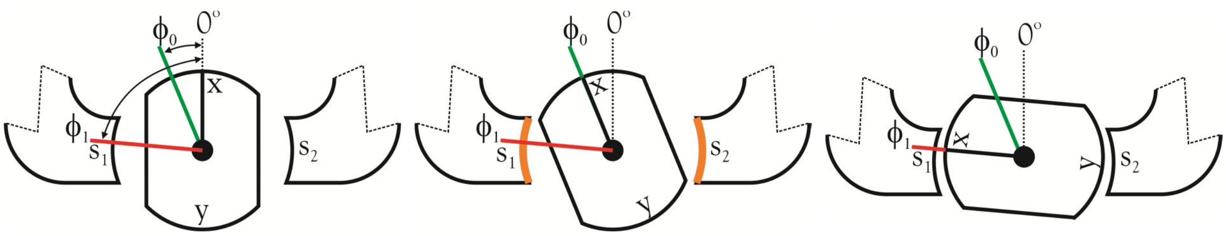



**Figure 1** A simple 2/2 pole single phase SR motor.




Unaligned position

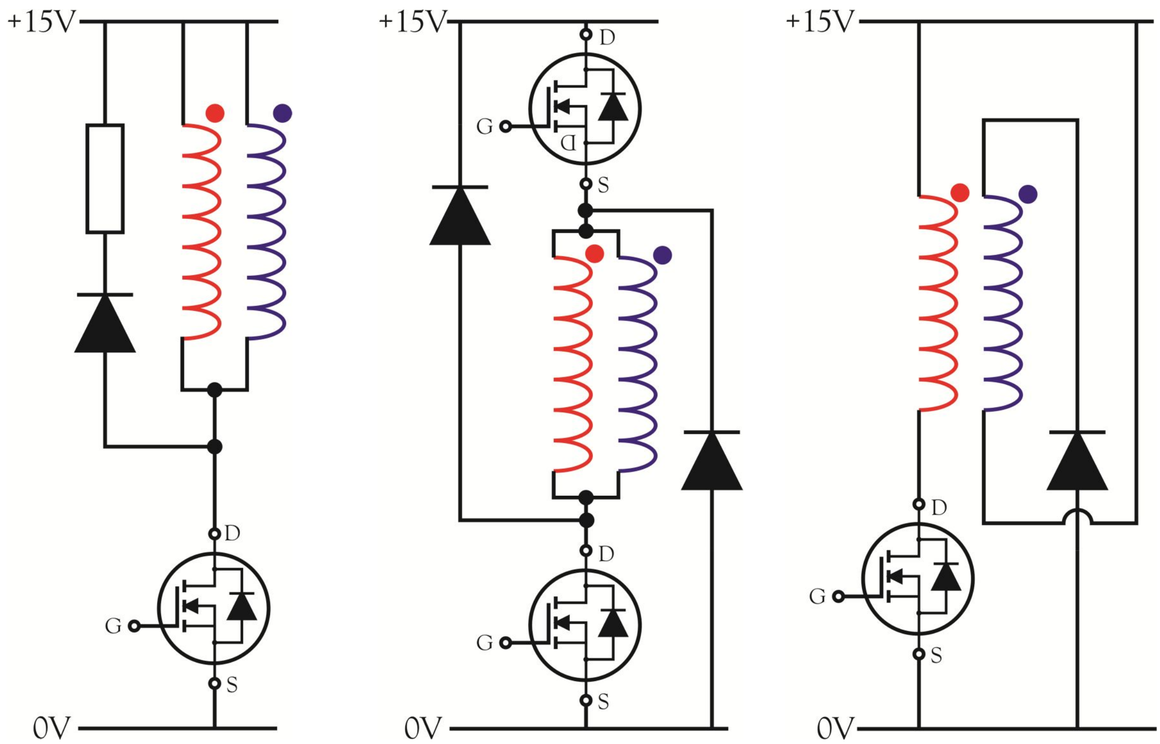
Stator is energised when rotor reaches $\phi_0$, rotor is attracted to position of maximum inductance $S_1$

Stator is denergised when rotor reaches $\phi_1$, rotor free wheels until the next energisation point $\phi_0$+180°.

**Figure 2** SRM Operation

Motoring torque is produced while the winding inductance is increasing, corresponding to an increasing overlap between stator and rotor poles. For the SRM used in this project this lasts for approximately 90°, followed by a period of decreasing overlap during which the torque is in the reverse direction. Due to the presence of winding inductance, it is beneficial to switch on the current before the start of overlap. This enables the current to increase to a "useful" value at the correct time. Likewise, it is beneficial to switch off before total pole overlap. This is rather like ignition advance on a car. A greater advance angle is needed as the motor speed increases. See additional background material on moodle for relevant theory and methods of controlling torque, speed and angle advancement.

Having built up winding current quickly; it is equally important to collapse it quickly. This represents extraction of stored energy that should ideally be returned to the supply, though it can be "thrown away" in a discharge resistor. Figure 3 shows three possible converter topologies, each has advantages and disadvantages. You should consider aspects such as complexity of construction, performance and efficiency when selecting which topology you will use during your project.




**a** **b** **c**

**Figure 3** Possible winding connections allow collapse of winding current when the transistor is turned off.

## 2 Overall project Aim

The overall aim of this project is to design and build a SR motor drive. The main elements required are shown in the block diagram shown in figure 4. Careful thought needs to be given to what function each element needs to perform and how it interfaces to any other element – e.g. signal type / level. The configuration presented in figure 4 is not the only solution, but can be used as a guide to get started.

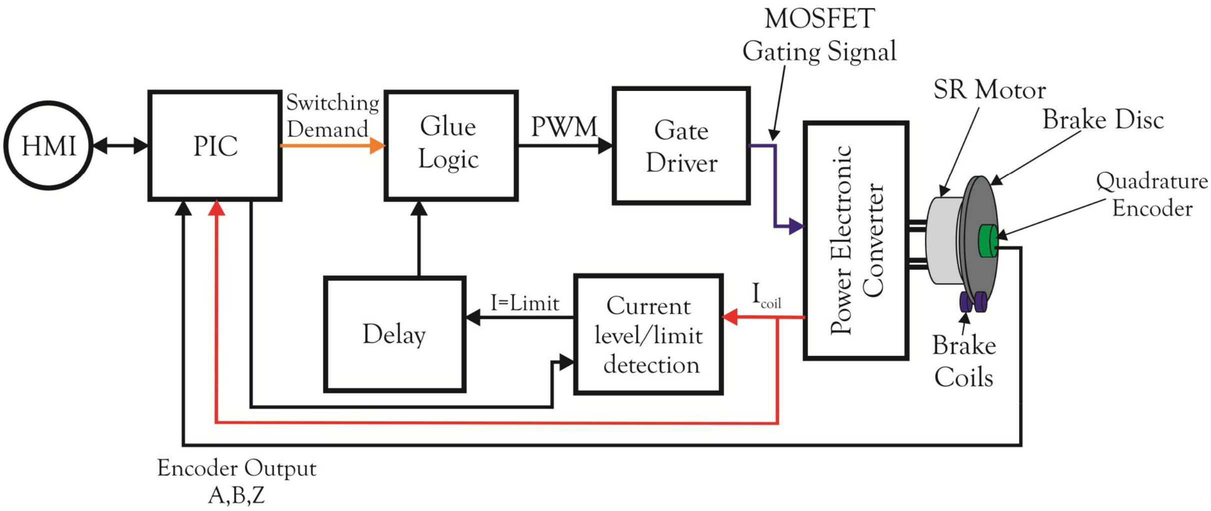



**Figure 4.** Block diagram of an example SR Motor Drive

## 3 Project Rig and Rig/Project Elements

### 3.1 Project Rig

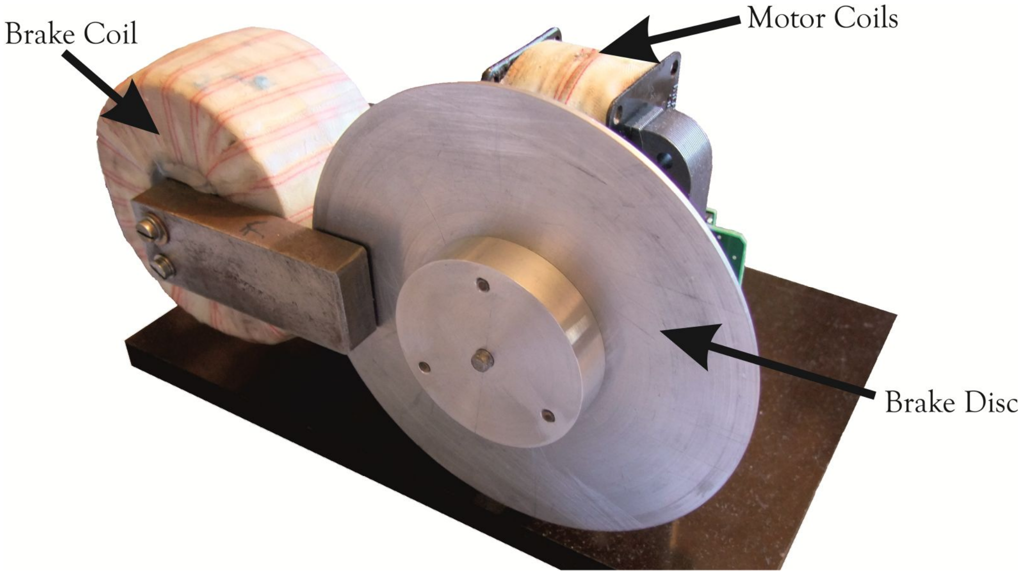



**Figure 5** Motor Rig Front View

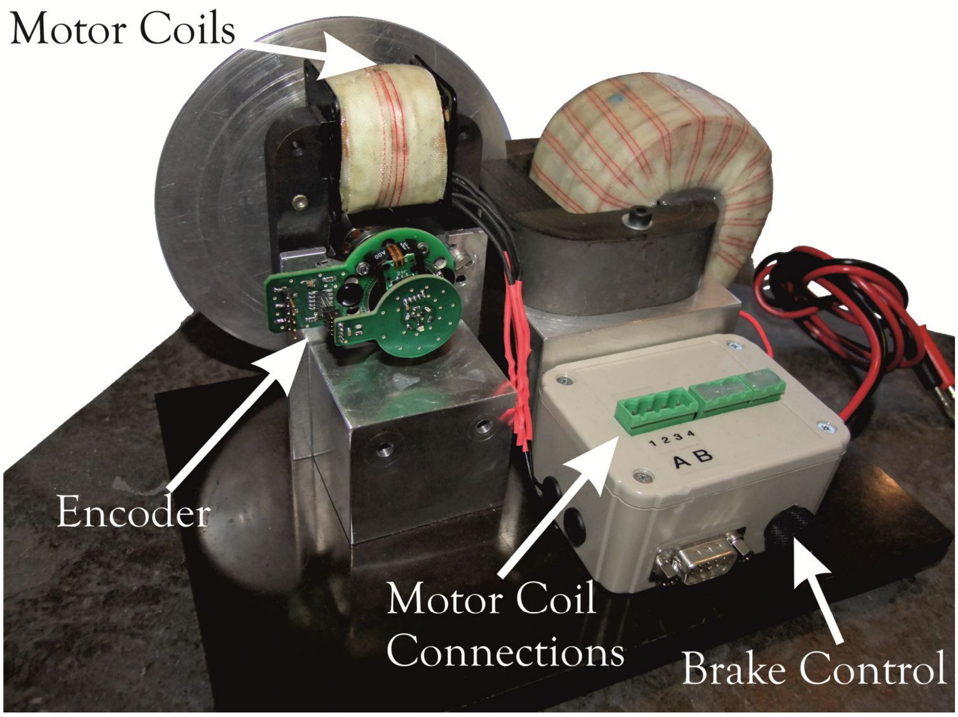



**Figure 6** Motor Rig Rear View

### 3.2 Software and PIC

The Microchip PIC18F46K20 Programmable Interface Controller (PIC), is to be used to control the motor. To do this the PIC needs to generate a switching signal for the MOSFET when the motor is at the correct position as explain in section 1.

Hint: You may want to look at the function of the timers, CAPCOM and interrupt peripherals of the PIC.

To be able to achieve this the encoder (section 3.3) needs to be interfaced to the PIC. An interface board has been designed to facilitate this. Figure 7 shows the PCB and connector signal definitions. This interface board is used to connect to the encoder, it provides power and allows the encoder signals to be connected to a selection of PIC I/O. It also makes certain PIC I/O available that are not present on the standard PIC board connector, which are useful for this project. An SPI controlled DAC is provided, this can be used to output 2 independent analogue voltage signals in the range 0-3.3V.

To use the interface if must be mounted on to the PIC board. This must be done **VERY CAREFULLY** checking the alignment of the pins and header before gently pushing the board together.

**DO NOT remove the interface board from the lab, they are needed for each session. Removal of a board from the lab, even accidently, may result in MARK PENALTIES for the group and or REDUCTION OF LAB ACCESS.**

Signals from the encoder will provide information about the position of the motor and this must be available to the PIC. Parameters such as the current in the windings may also be needed by the control software.

The design of the control software will form a major part of the project. The programs written must be included in the project report and *marks will be awarded for good software engineering practice*. Therefore, programs should be well structured and well documented in the report.

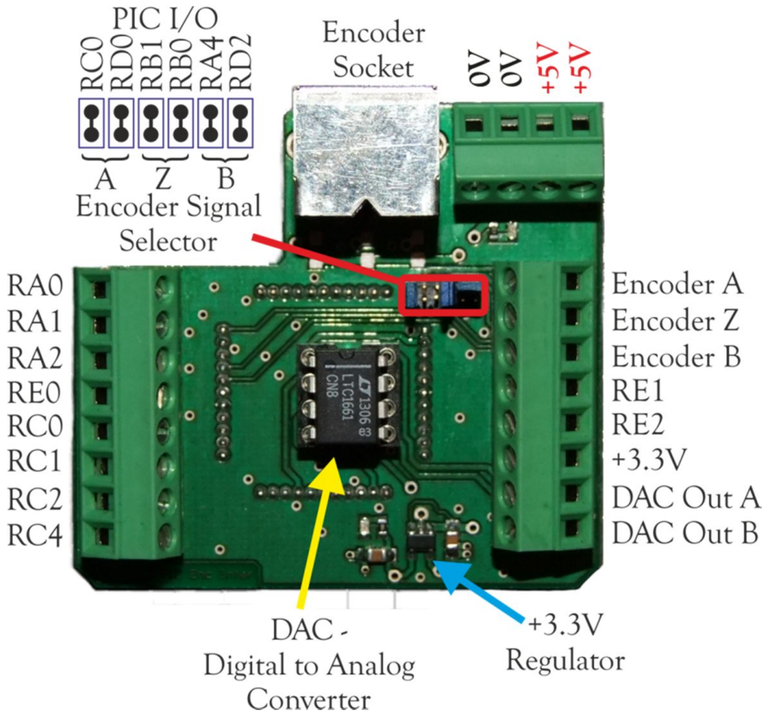



**Figure 7** PIC Interface board pin out

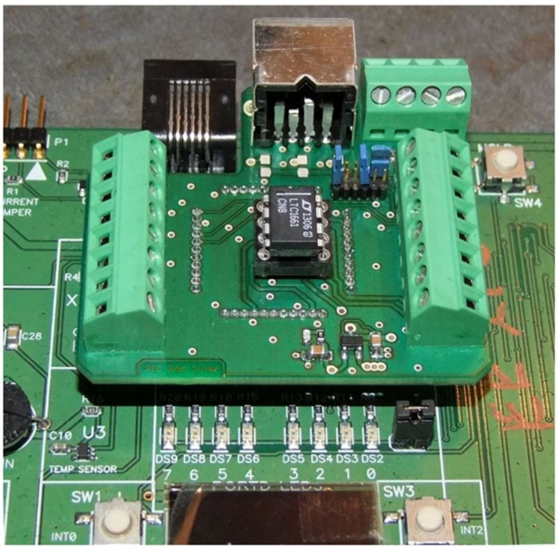


**Figure 8** Interface Board Mounted on PIC

### 3.3 The Motor

This was originally a shaded pole induction motor. The shading rings have been removed and the stator bore cut to give salient stator poles. (All motors have been so adapted identically.) The bifilar winding has an appropriate resistance and inductance for a 15V supply. **However, if 15V is permanently applied it will overheat and be damaged**. The winding inductance varies between $L_{max}$ and $L_{min}$ at twice the rotational frequency. The motor can be loaded with an eddy current coil, which acts on the metal motor disc. The resistance of a single winding is approximately 0.7Ω, the unaligned inductance is approximately 3mH.

The ends of the two motor windings are available on the green 4 way connector as below.

| | Dotted end (figure 1) | |
|---|---|---|
| **Coil A** | **1** | **2** |
| **Coil B** | **3** | **4** |

### 3.4 The Position Detector

The motor rig has a 3 channel incremental shaft encoder. Channels A and B are 90° offset. Channel A and channel B each produce 500 pulses per revolution (ppr). The Z pulse (which counts one full revolution) is used to decode the position of the rotor with respect to the stator. This will need calibrating depending on the motor rig you are using. The waveform of the channels is available in the data sheets and given in Figure 3. The encoder plugs directly in to the PIC interface board, the A, B and Z signals are available on one of the connectors to be used in any circuits you feel are needed. One example is if you want to detect motor direction.

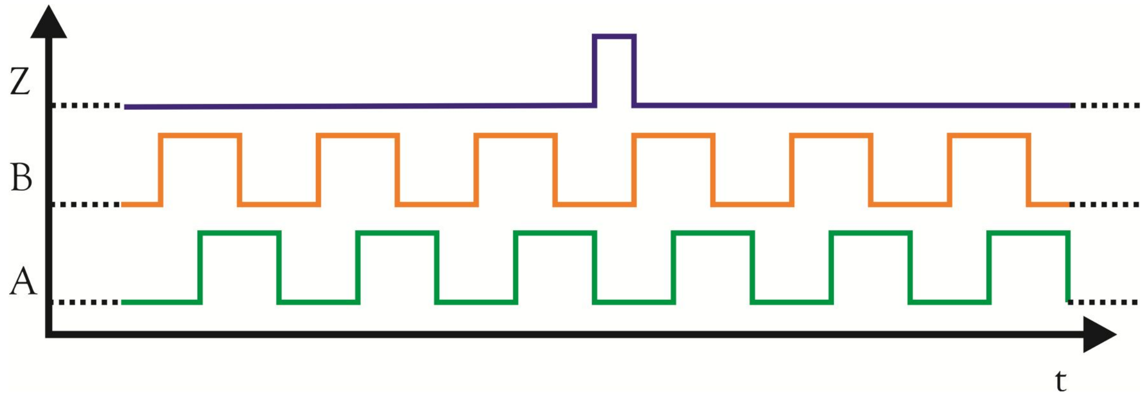



**Figure 9** Encoder channel output waveforms.

### 3.5 The Copper Strip Board Circuit

Marks will be awarded for neat layout as well as performance.

See demonstration unit for example.

**Note:** A copper strip should not be used for currents > 3A, consider reinforcement of high current tracks.

**Figure 10** Example of track reinforcement using solder

## 3.6 Power Device MOSFET

One of the main devices in the construction of a power electronic circuit is the power switching device. In this project it is a MOSFET, shown in figure 3. This device is used to control (switch) the current in the stator winding on and off. Through proper switching of this device control over the current in the stator can be achieved.

A Power MOSFET is switched (gated) by applying or removing a voltage between the gate and source, $V_{gs.}$ It is important that the correct voltage levels are created to guarantee turn-on and turn-off the device. See data sheet for information in threshold voltages.

To aid the proper gate driving of the MOSFET a gate driver IC, HCPL 3120, is available to be used. See data sheet for operation and example application circuit.

There is a vast amount of material available on gate driver design and hints on power electronic circuit construction. Most device manufactures have application notes, Semikron (http://www.semikron.co.uk/) is a good one. Also most power electronic books have sections on practical issues, e.g. managing stray components, snubber design and layout considerations, See Elements of Power Electronics by Phillip T. Krein

## 3.7 Protection

Any controller that results in a peak transistor (power MOSFET) current under any operating condition, including stationary, in excess of 8A will fail to satisfy the objectives. This implies that *transistor current must be measured* and the transistor turned off (permanently or briefly) if, say 7.9A is exceeded, as measured using an oscilloscope. Resistors of 0.1Ω are available for current measurement.

The circuits shown in figure 3 may be modified to provide current measurement and hence control. However care must be taken in the design to avoid undesirable side effects such as high frequency (10's of MHz) oscillation in the motor current.

Most students spend (and waste) much of the project time trying to get an effective current limiting circuit working even though at first hand this seems a straightforward task compared with the rest of the project. You will not produce a suitable design unless you think very carefully about the voltage waveform produced across your current sense resistor (assuming you use one). Many students in the past have found that their circuit caused the transistor to switch at very high frequency and they were not able to understand or easily remedy this. ***The importance of the current limit circuitry cannot be over emphasised and the correct operation of the current limit should be your first objective*.** In order to ensure your project starts successfully it is strongly recommended that the following circuits are checked by a demonstrator before you progress to building the next circuit stage.

1. A built circuit giving digital indication (e.g. through a comparator) that the transistor current exceeds the peak limit.

2. A built circuit which is triggered by the circuit in part 1 and disables the power device for a period of time (to allow the stator current to reduce) e.g. a monostable timer.

3. A logic interface circuit which glues the disable signal in part 2 and the turn on signal from the processor together to give the desired function. (Start from a truth table)

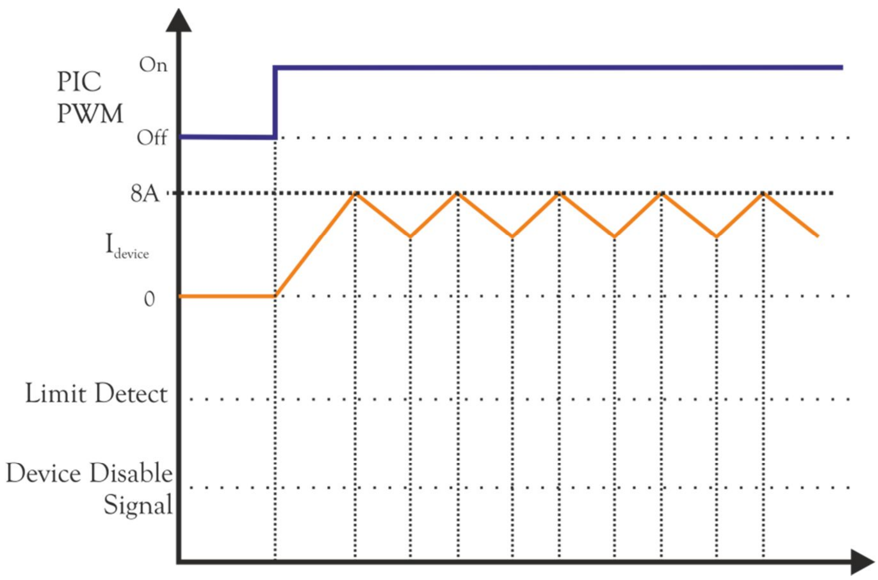



**Figure 11** Example device current during current limit.

## 3.8 Interconnect Board

The interconnect board which sits inside the beige box, beside the shaft encoder, houses the brake coil drive circuit as well as the break-outs for various parts of the Motor rig itself.

## 3.9 Brake Coil

The brake coil circuit is housed in the box with the motor coil connector. The coil of the eddy current brake is energised from the 10A supply. The brake coil is driven by a Darlington transistor on which the base current is varied by a 4k7Ω potentiometer. The potentiometer is accessible from the front of the box by the user.

# 4 Project Equipment

## 4.1 Components 1 set per group

Each group will be supplied with:

1. A copper strip board on which the electronic circuits will be built.
2. Two power MOSFETS (P36NF06) and diodes (BY397), which may be used in any configuration.
3. A HCPL 3120 2A gate driver and opto-coupler
4. 2 core cable for motor and power supply wiring, 8A connections.
5. 1 Red and 1 Black 4mm banana plug for 15V connections.
6. 4 way connector for motor rig.
7. 0.1Ω 5W Resistor
8. Heatsink.
9. A collection of other possible useful components. – Other general components can be found in the lab carousal.

## 4.2 Lab Equipment – To remain in the lab

1) SR Motor rig, which includes brake, encoder and encoder to PIC cable.
2) Encoder / DAC PIC daughter board.
3) 15V, 10A power supply for the motor and brake
4) 5V power supply
5) Soldering Iron
6) Basic tool kit

## Construction Advice and Hints

Carefully think about your designs, but prototyping is a good way of moving forward i.e. learning through experience.

Plan your stripboard layout, power electronic layout can be very critical to good circuit operation.

Stripboard neatness may seem strange, but it helps in debugging and often reduces errors.

Decouple all IC's and follow any special requirements for IC's given in datasheets. Often the difference between a working and not working circuit.

Learn to use oscilloscopes; they are a vital tool for checking operation.

Build circuits in sections which can be individually tested and then linked together.

# 5 PROJECT OBJECTIVES

There is a series of objectives of increasing sophistication. Excellent performance in a less sophisticated mode may be judged more worthy than poor performance in a highly sophisticated mode. All groups are expected to meet the simpler objectives. Whilst success is not obligatory it is hoped that most groups will aim to achieve all objectives.

## 5.1 Objective 1 – Current Limiting

See section 3.7 protection.

## 5.2 Objective 2 – Drive User interface

In this objective you are tasked with creation of a user interface using buttons, LEDs and the PIC OLED display. You should look at all the project objectives and create an interface which can be used throughout the project.

The display should be used to indicate the firing angles currently being used and the current speed. The input keys should be used to input the desired firing angles and the speed in later objectives. The effective use of the input keys and display will contribute marks to the appropriate objective as well as in their own right.

The interface at a minimum needs

- **OLED Display based menu**
- **Minimum of 6 push buttons** (DO NOT use the ones mounted on the PIC board)
- **LED's to indicate the Drives status** (Not using the ones mounted on the PIC board)
  - Drive Powered
  - Motor Running
  - Direction of rotation

<u>You want to complete **Objective 1 & 2** within the first **3 weeks**.</u>

## 5.3 Objective 3 – Motor Spinning

This objective is to make the motor spin under software control. If this is as far as you get then you should endeavour to produce a high torque over the operating range of the motor. The angles $\phi_0$ and $\phi_1$ which are pre-selected as constants in the software will have to be a compromise to cover the whole speed range. At this stage, there is no requirement to control the speed of the motor. The breaking effect of the load should be used to reduce the motor speed to that desired.

## 5.4 Objective 4 – Motor Direction Detection and Control

This objective is to detect, display and control the motor direction. Once rotating you should be able to change the direction of rotation with a press of a button. Using the encoder design a method of correctly detecting the current motor direction and display on the interface.

## 5.5 Objective 5 – Online Variation of firing angles

As objective 3, but with the ability to change $\phi_0$ and $\phi_1$ while the motor and software are running. This information will have to be input to the PIC. At this point in the development, it is more straightforward to find out how the motor behaves as the angles are changed and to produce torque vs angle data. There is no requirement to control the speed of the motor. The speed will be determined by the torque produced by the motor and that produced by the brake.

## 5.6 Objective 6 – Torque control

For this objective a method of controlling the torque of the motor is to be designed and implemented. There are a range of methods to achieve this, see the background research material for ideas. The main principle is to regulate the mean current in the motor winding to a variable value. There is no requirement to control the speed of the motor. The speed will be determined by the torque produced by the motor and that produced by the brake.

## 5.7 Objective 7 – Angle Advancement

As 5.2, but where $\phi_0$ and $\phi_1$ are automatically varied as a function of speed (angle advancement) to provide, hopefully, optimum torque whatever the speed.

## 5.8 Objective 8 –Closed loop speed control

The speed is automatically regulated by a closed loop system irrespective of variations in load torque. For this objective you should have achieved torque control, this will allow you to have a nested control loop system.

## All Objectives and Deadlines

To obtain the largest possible torque for a 15V supply current not exceeding 6A (mean value). Current drawn by the electronic signal processing circuits is not important.

As was explained in Section 3.7 the current limit is vital to the successful completion of the project. It is important that this part of the project is completed early**.** Failure to do this can result in serious delays to the rest of the project.

The PIC daughter board contains a 2 channel DAC, this may be useful during the project. It can be used to view PIC variables on a scope for debugging or results, it can also be used as part of the control system for torque and speed. There is a simple DAC example program, which outputs some square waves, this is just an example and is to be modified. Please note that using the DAC and the OLED at the same time can cause errors, but these can be simply overcome by proper ordering of DAC and OLED operations.

Obtaining a spinning motor is also important, as data will need to be gathered on the performance of your motor to allow progression to the later objectives of the project.

For objectives 3 to 7, the speed will be determined by the loading system. The breaking torque should be gradually increased until the motor is operating at the desired speed in the approximate range 1000-6000 rev/min.

For objective 8 the desired operating speed will be input and the loading system will simply apply load torque until the 6A supply current is reached or the speed control fails.

Ed Christopher, H62EDQ [Jan 2015]

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