<u>Use of Induction Motors in the Home Workshop</u> **by R C Minchin**

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DOCUMENT ISSUE STATUS

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1	September 2009	First issue of document
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Chapter 1 Motor Types

Majority of the electric motors we find in the home workshop will fall into three types.

1. Low voltage DC motors as found in battery operated cordless tools usually rated at less than 50 Watts.

2. Brush or universal motors in corded hand held power tools (these are called 'universal' as they will run from either AC or DC although majority will be run from AC in our workshops) these are typically rated between 50 Watts and 1500 Watts.

3. Induction motors run on AC power only, and are usually designed for a specific AC frequency (50Hz in Europe, 60Hz in US and some other countries). They may be divided into two main classes: single phase motors (as used in most domestic supplies) or three phase motors designed to run from industrial 3-phase supplies. Motors employed on hobby & trade woodworking machinery are generally rated between 250 Watts and several thousand Watts (or kW for short).

Motors are machines in their own right, converting electrical energy into mechanical energy, and like all machines they are not 100% efficient. Most of the wasted power appears as heat and must be removed, usually by fan cooling built into the motor. In the universal motor, which is generally designed for a high output-power-to-size ratio, a significant amount of power is used by the cooling fan(s), which are required to keep the relatively small motor cool. Overall efficiency is typically around 50%. The combination of high-speed fans and brushes/commutator gives rise to significant noise and hence these motors are generally regarded as undesirable in our workshops. They are also usually designed for cheapness rather than efficiency, and the large amount of heat produced means they are not continuously rated: often the higher power versions have thermal cut-outs built in to protect them against overheating thus preventing continuous use.

I shall mainly concentrate on Induction motors as that is where most uncertainty seems to lie in the minds of some home workshop users.

Power Rating

Induction motors are usually rated in terms of their **power output**. More modern types are rated in Watts or kW, whereas older motors will often be marked in horsepower or hp.
1 horsepower is equivalent to 746 watts, although 750 watts is more often used as an approximate conversion factor.

kW	hp
0.18	1/4
0.25	1/3
0.375	1/2
0.55	3/4
0.75	1
1.1	1.5
1.5	2
2.2	3
3	4

Table 1 Common modern induction motor power ratings

Single Phase Motors

Figure 1 shows a typical single phase motor. This form of construction is known as Totally Enclosed Fan Cooled or TEFC. Under the cover on the left hand end is a fan that blows air over the fins on the body. Note that “Totally enclosed” means that **no** external cooling air is drawn through the motor “innards” to directly cool the windings: the heat generated internally is conducted out though the case and dissipated by the fins. This type of construction is preferred in a dusty environment. The rectangular box houses the connection terminals. Note also the bulge on the top/front that houses the starting capacitor.

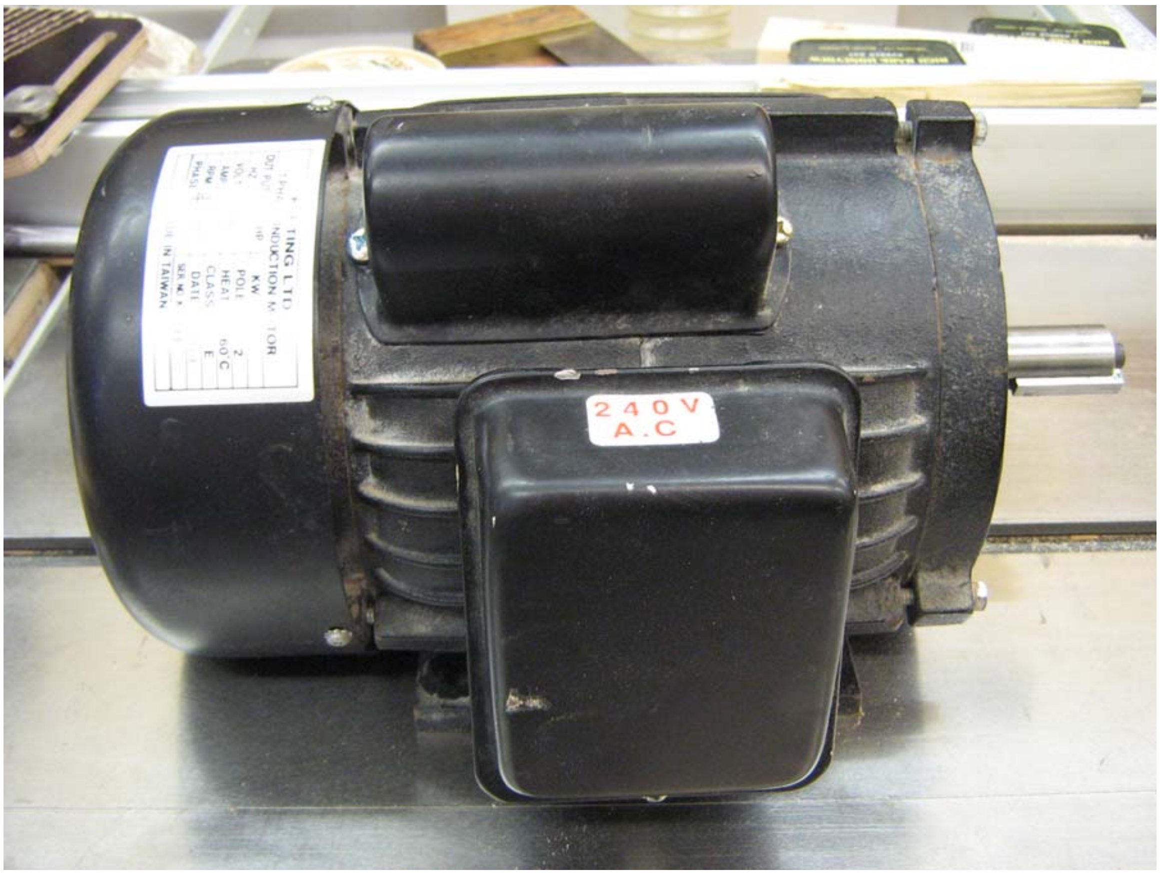


Figure 1 A typical modern single phase motor.

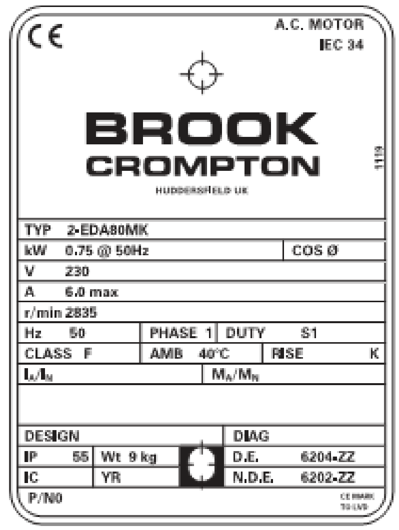
The overall efficiency of an induction motor normally much higher than for a high-speed brush motor, and the larger the motor, the more efficient they become. Typical efficiencies are shown in Annex D. Many readers may be familiar with the method used to calculate power in a DC circuit by multiplying the voltage by the current. This does not work for AC motors, because the current is not usually in phase with the voltage.
This will be dealt with later, but save to say for now, the product of the voltage and maximum current on the rating plate on a motor will be considerably higher than the power output of the motor.
However, the circuit providing power to the motor must be able to supply

- the voltage and the current on the rating plate on a continuous basis
- up to five times the rated current for a short time during starting

.

The Single Phase Rating Plate

The left hand picture in Figure 2 shows the rating plate of the motor shown in Figure 1. In this case the power is quoted in horsepower despite being a modern (1999) motor.
From Table 1, this is equivalent to 2.2kW
The design frequency (shown as “HZ”) is 50 Hz (or 50 cycles per second) which is standard UK mains frequency.



Example of rating plate

Figure 2 A typical single phase motor rating plates (Taiwan & Europe)

The voltage, 240 and current, 15 amps suggests 3600 watts does not imply appalling inefficiency but does mean that such a motor will need a dedicated circuit from the fusebox rated at 15 amps or more. 16 amps is a standard circuit breaker value. The starting current is likely to peak well over 25 -30 amps so a type C breaker[1] is recommended, but it is important that the installation is suitable for such breakers. If in doubt get your installation tested.

This motor is a 2-pole machine, which means there are 2 magnetic poles that govern the speed of rotation. The theoretical speed of the motor is given by

$$\text{Speed (revs/}\textit{second}\text{)} = \frac{\text{Supply frequency (50 Hz)} = \text{50rps}}{\text{Number of pole } \textit{pairs} \text{ (1)}}$$

Therefore revs/*minute* = = 50 x (No of seconds in 1 minute) =3000rpm

However, the actual full-load speed is always lower by a small percentage (typically 3 to 6%): in this case 2840 rpm. This difference is called the ‘slip’. Note that off-load, the motor runs very close to the nominal speed, i.e. the slip reduces to typically less than 1%. Hence the speed regulation of induction motors is very good (when compared to the brush/universal motors found in portable power tools).

[1] Slow action: does not respond quickly to transient overload.

Poles	Full Load Speed (rpm)	
	@ 50Hz	@ 60Hz
2	2850	3420
4	1425	1710
6	950	1140
8	700	840

Table 2 The relationship between poles and shaft speed

A couple of things to note about poles.

1. Poles always come in pairs and because there always at least two, no induction motor running on 50 Hz can run faster than about 2850rpm
2. Virtually all motors found in the workshop are either 2 pole or 4 pole

The temperature rise above ambient can be 60 degrees. With modern insulation (in this case Class E) it is quite common for motors working hard to be too hot to touch. This is not a problem. If however a motor is only lightly used and runs hot after only a few minutes then this should be investigated. More details of insulation classes and their rated temperatures are given in Annex A
Most motors are rated for continuous use: this is usually indicated by a "**Rating**" or **"Duty"** box on the name-plate which will be labelled "**S1**" or "**Cont**". Motors designed for machines that are used intermittently are (historically) labelled "**Int**": more recently "S2" or "S3". These motors will overheat if used continuously or beyond the duty cycle indicated (See Annex C).

Single Phase Motor Winding Configurations

All single phase motors have two windings. One is designed to provide the main drive and is known as the 'run' winding and the other is used to define the direction in which the motor runs and is commonly known as the starting winding.
Most motors have a capacitor associated with the start winding and many have an automatic switch inside the motor which changes the configuration when the motor gets up to speed – usually to disconnect the starting winding.
This switch can usually be heard to operate as the motor slows down. Firstly a click followed by a slight rubbing noise at shaft speed. This is often referred to as the centrifugal switch.
The Figure 3 shows a number of different configurations of run, start, switch and capacitors found in single phase induction motors.
This is included more to show how many variations there can be more than anything else.

Most applications in the workshop need a reasonable starting torque to overcome the mechanical resistance of belts and bandsaw blades. Motors with both switches and capacitors provide good starting torque.

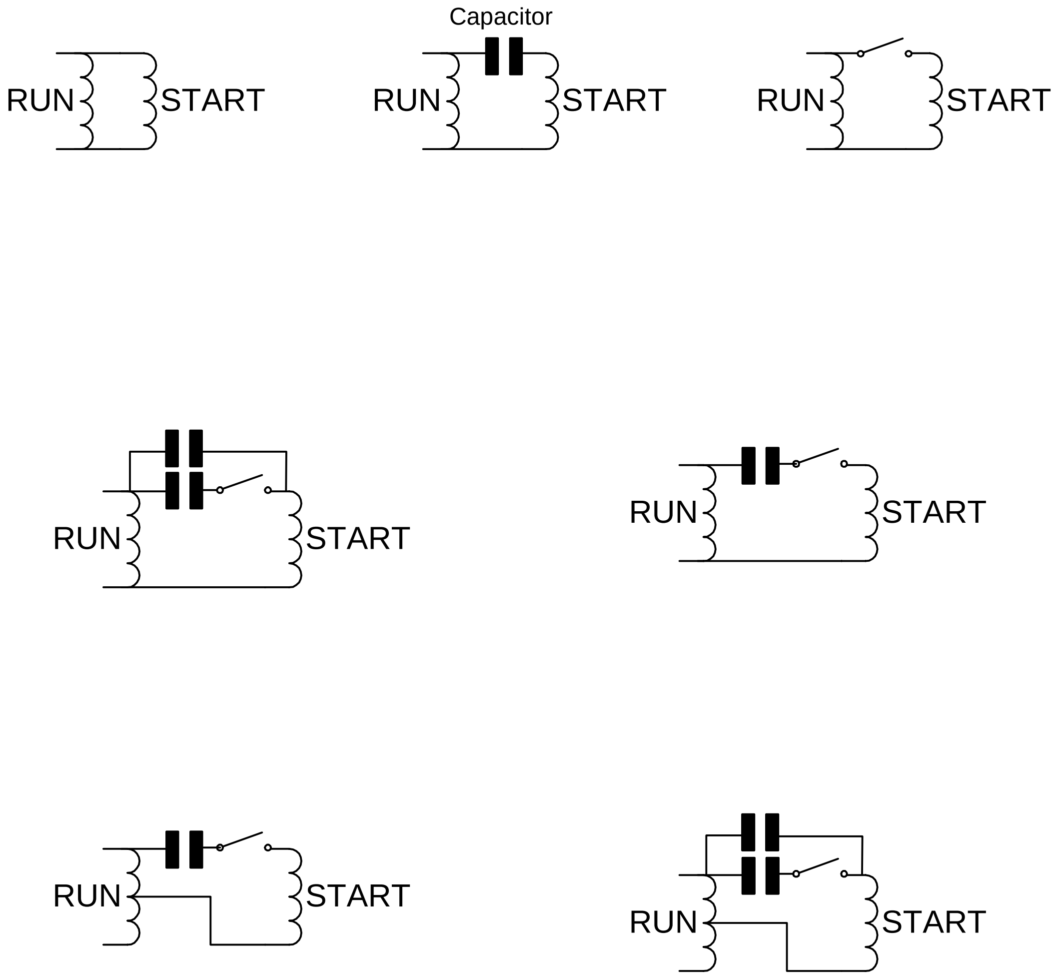


Figure 3 Different electrical configurations of single phase induction motors

Most single phase motors can be reversed by swapping the connections to the start winding with respect to the run winding. However not all motors have sufficient connections brought out to allow this to be done, in some cases they can be found by opening up the motor but in others the connections are permanently made inside the windings and will need expert attention to reverse them.
When buying a single phase motor it is essential to check that it either rotates in the correct direction for your application or is readily reversible.
Recently at least one manufacturer, ABB is supplying single phase motors with electronic switching of the starter winding. These switches are silent in operation so do not make the characteristic sounds associated with most single phase motors mentioned above. Further information on these motors is given in annex F

Three Phase Motors

Figure 4 shows a typical 3 phase motor of the TEFC type. Note the absence of the capacitor on the side. No three phase motor will have a capacitor.

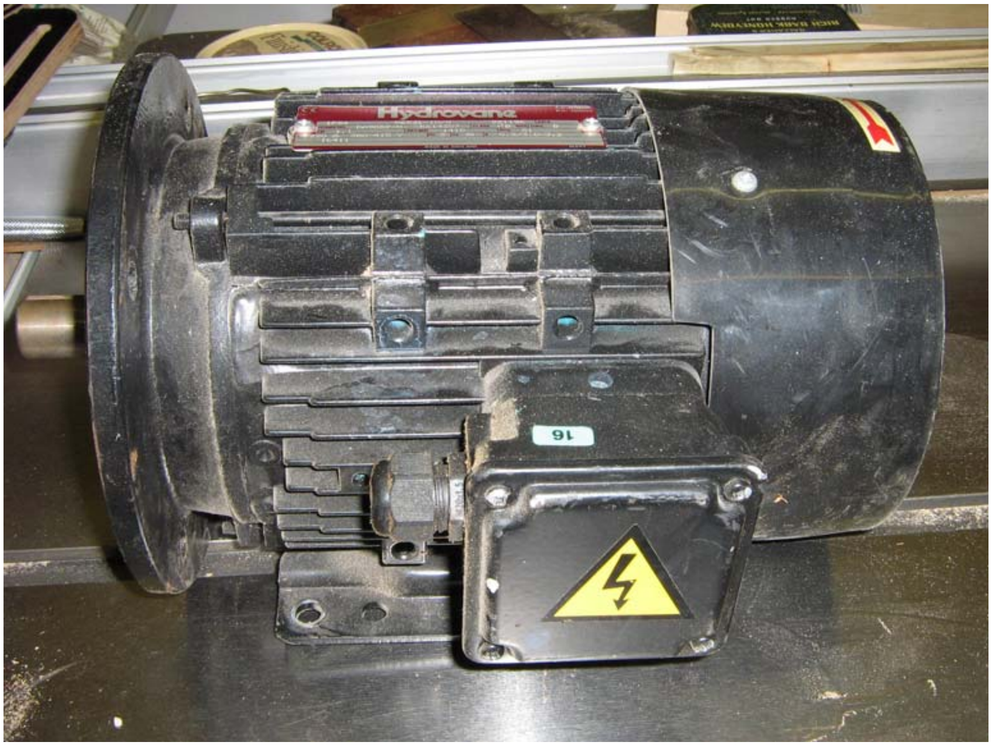


Figure 4 A TEFC 3 phase motor

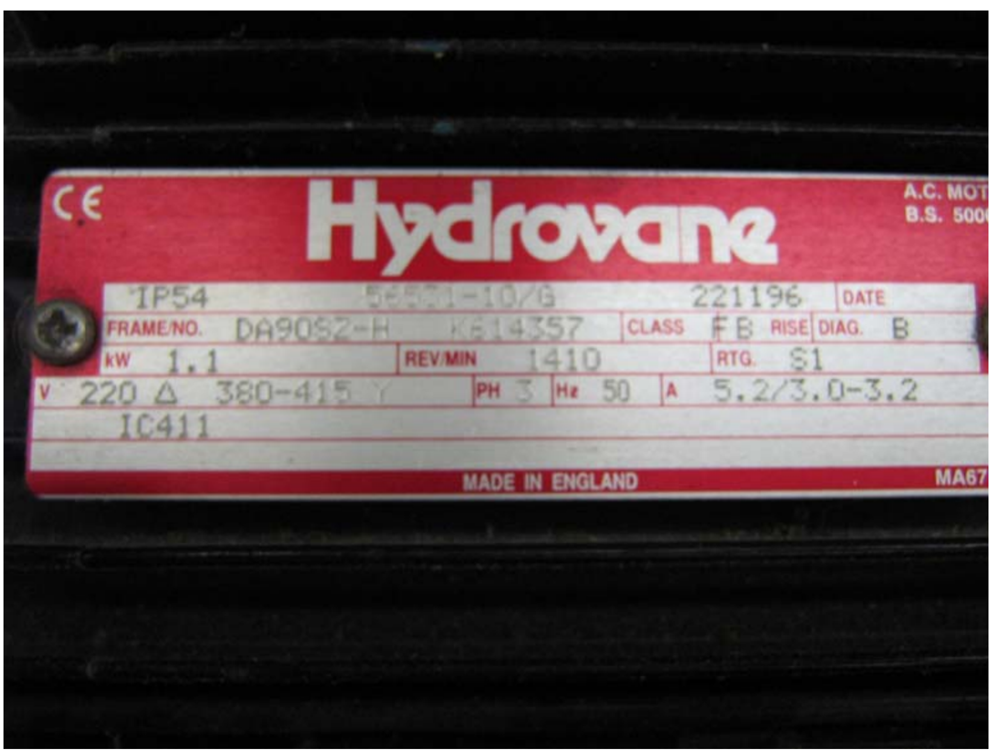


Figure 5 The Rating Plate from the motor in Fig. 4

The 3 Phase Rating Plate

This motor is 1.1kW (1.5hp) and runs at 1410 rpm so it is a 4-pole machine - see table 2.
The voltage is marked as 220 with a triangle or Greek capital Delta and 380-415 volts with a capital Y. The Y mode is often referred to as star. This motor is a dual voltage motor, which makes it the most versatile type for running from single phase supplies.
When conFigured in Y mode, the motor draws less current from higher voltage supplies. The plate tells us the current draw per phase for different voltages and modes as follows

Mode	Voltage volts	Current amps
Delta, Δ	220	5.2
Star, Y	380	3.0
Star, Y	415	3.2

The frequency is stated as 50Hz so is designed for UK/European mains supplies.

Changing between Star and Delta modes is very simply done by moving three links – usually metal straps inside the connection box.

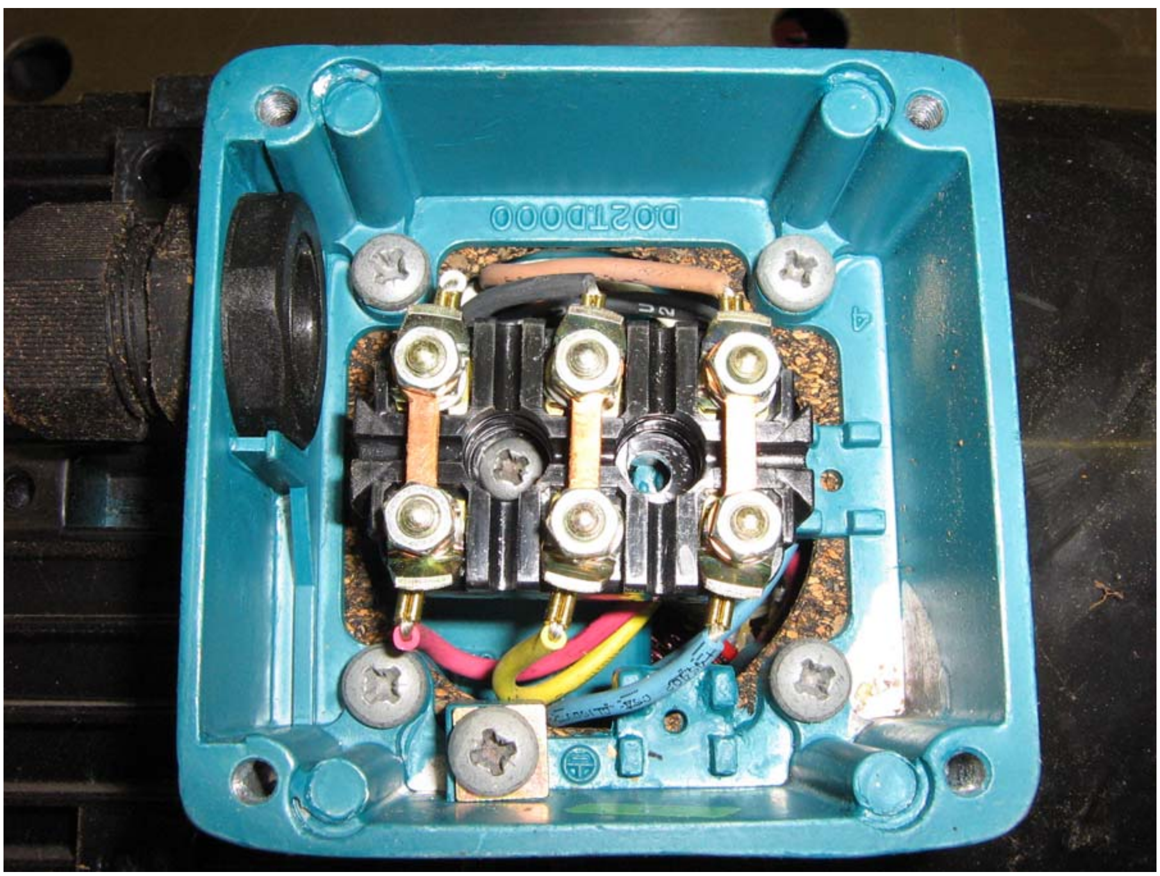


Figure 6 Inside the connection box – wired to Delta (low voltage) mode

Figure 6 shows the characteristic 6 terminals of a dual voltage, 3phase motor connected for Delta mode by three vertical copper straps. The incoming three power wires (not shown) are connected to the bottom three terminals in this case, Red, Yellow and Blue. These are common colours but others are used.

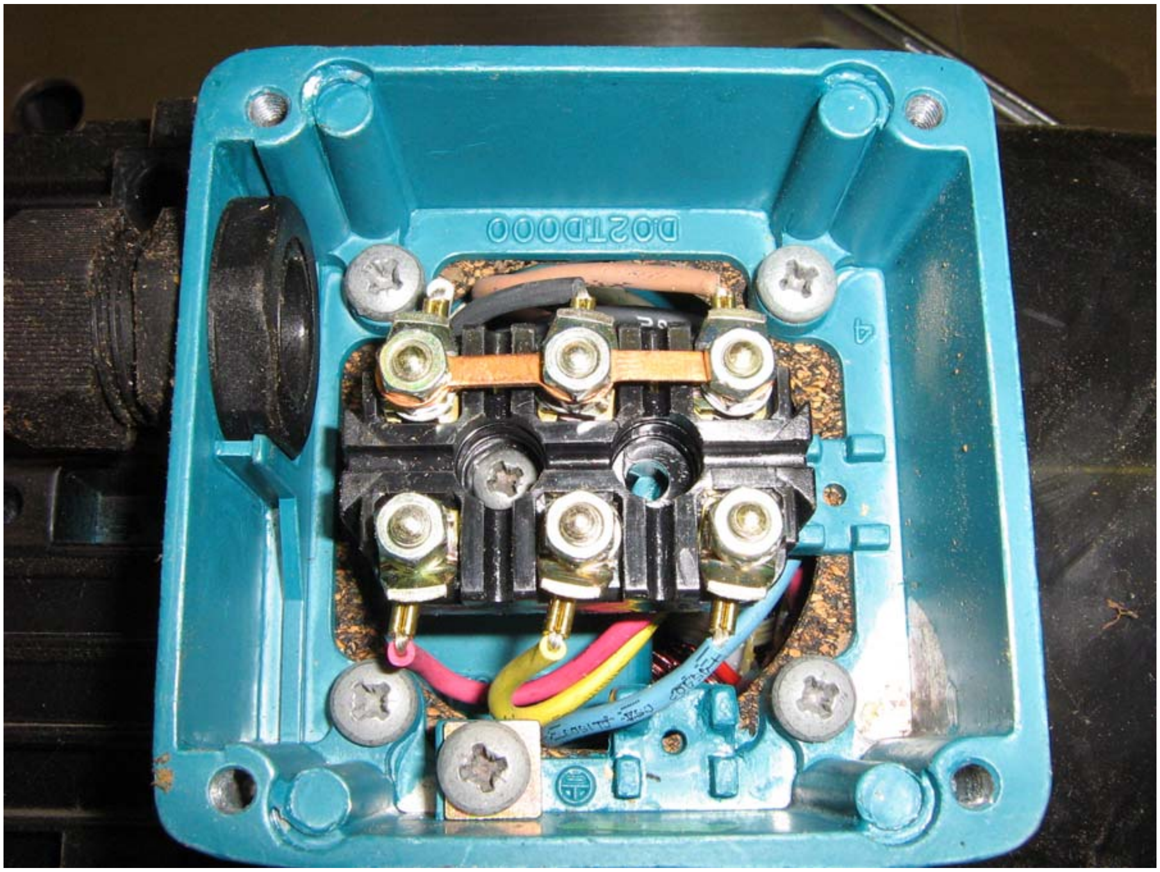


Figure 7 Inside the connection box – wired to Star (high voltage) mode

The straps are moved to the positions in Figure 7 to run the motor in star mode. Although only two straps are needed, it is normal to park the second and third strap together so that all three are retained should the motor ever need to be put into Delta mode.
As in Delta mode the incoming supply is connected to the lower three terminals; Red, Yellow and Blue.

Not all motors are dual voltage and older ones tend to be fixed in Star mode and only have three terminals available in the connection box. These will always be 415 volt motors.

The names Star and Delta come from the diagrammatic representation used for the windings. Figure 8.1 shows the windings of a three phase motor in Delta and Star modes

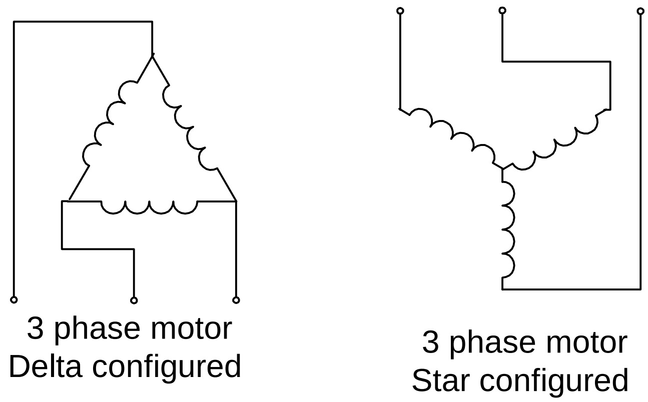


Figure 8.1 Winding Configuration

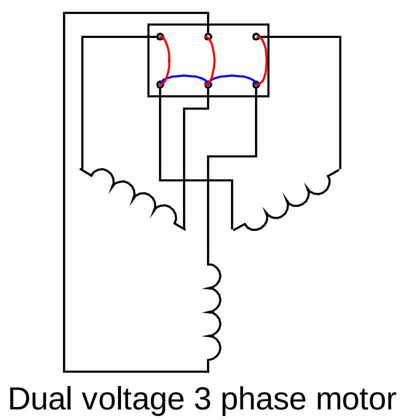


Figure 8.2 6 Terminal winding configuration

Fit RED links for Delta, BLUE links for Star

Tracing the wiring through in Figure 8.2 for both Red and Blue links it can be seen that the Delta and Star configurations of Figure 8.1 are obtained.

Essentially nearly all three phase motors up to say 3 kW are configured as described above. So compared to the single phase motor we have far fewer configurations, no switches and not a capacitor in sight. Just add three phase power and they will start up by themselves. For all three-phase motors, to reverse the direction of rotation, simply swap any two of the three incoming “phase” supply wires over.

Chapter 2 Starter Switches & Motor Protection

Direct On Line Starter

In domestic applications circuit protection is partly in the consumer unit as a re-wireable fuse or MCB (Miniature Circuit Breaker) and partly in the plug as a 1” cartridge fuse.
Running large motors for machines in the home workshop each circuit has its own MCB/fuse in the fusebox and this protects the cable to the machine. The motor is protected by an overload relay inside the starter switch.

Starter switches come in a number of shapes and sizes. At first sight they might appear to be a rather large box for a switch however, comprehensive starter will:-

1. Stop and start the motor
2. Prevent the motor restarting after the power has been interrupted (NVR or No Volt Release)
3. Protect the motor against long/medium term overload (overload relay or Thermal Trip

Manufacturers have a variety of implementations of starters and different names for them. Quite often they are referred to as DOL Starters. This stands for Direct On Line and simple means the motor starts by having the supply switch directly to the motor. (Much larger motors have more complex methods to start them gently hence the name.)

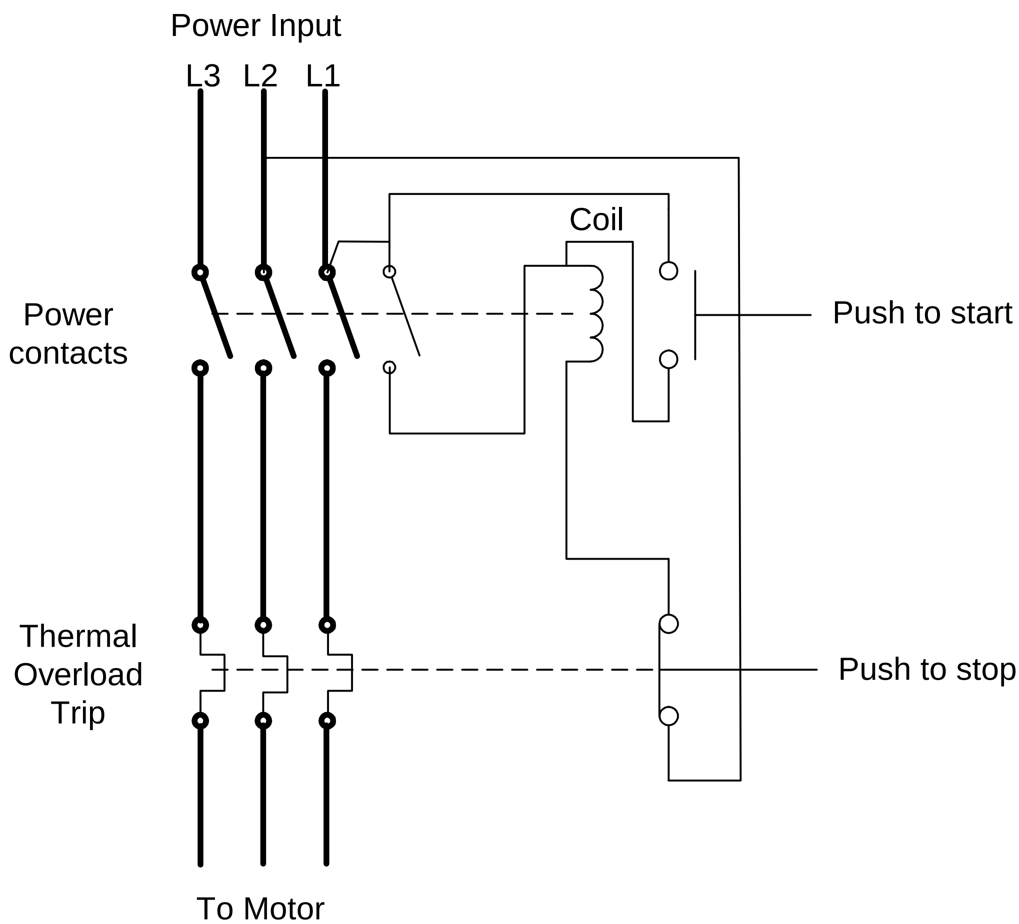


Figure 9 A typical 3 phase DOL Starter circuit diagram

Figure 9 shows the basic components of a DOL starter with NVR and Thermal protection relay. The main power path is shown in bold. Three normally open heavy current switches connect the supply through to the thermal overload relay. These have heating elements that warm up when sustained high current passes through and trips the stop switch on the bottom right if any of the supplies is overloaded. The trip does not trigger for short-term overloads or during starting. The overload relay should be selected to match the current range of the motor and further adjusted to trip at about 20% more than the current on the motor rating plate.

In addition to the high current contacts there is an auxiliary low current contact that keeps the coil energized which in turn keeps all four contact closed. If the incoming supply fails then the switches open and will not close again until the start button is pushed once more. This is known as No Volt Release or NVR. The stop button is a normally closed switch which when pushed momentarily will break the coil circuit and the main switches will open.

The coil is powered from the incoming supply and must be designed for that voltage. In the case of 3 phase power, the coil will be rated to run from 380 to 440 volts.

The single phase starter switch is almost identical apart from having one less switch pole (delete L3 in Figure 9) and the coil must be designed for 220-240 operation. L1 and L2 above become Line and Neutral.

If a 3 phase starter is used on 240 volts, the coil will be very unlikely to hold in and even if it does it will not provide enough holding force to close the contacts properly and lead to overheating.

Furthermore, the Thermal Protection relay may not have enough adjustment range to for the single phase motor and lead to tripping.

There are many manufacturers of these DOL starters and several are modular such that in theory, you can swap coils and buy different overload relays. However finding suppliers of matching parts for old starters could be difficult and end up cost nearly as much as buying the correctly rated complete units from the retail discount suppliers such as Machine Mart and Toolstation to name but two.

The following pictures show views of some typical DOL starters with overload protection.

Figure 10 A typical older DOL starter

Fig 11 Starter ratings

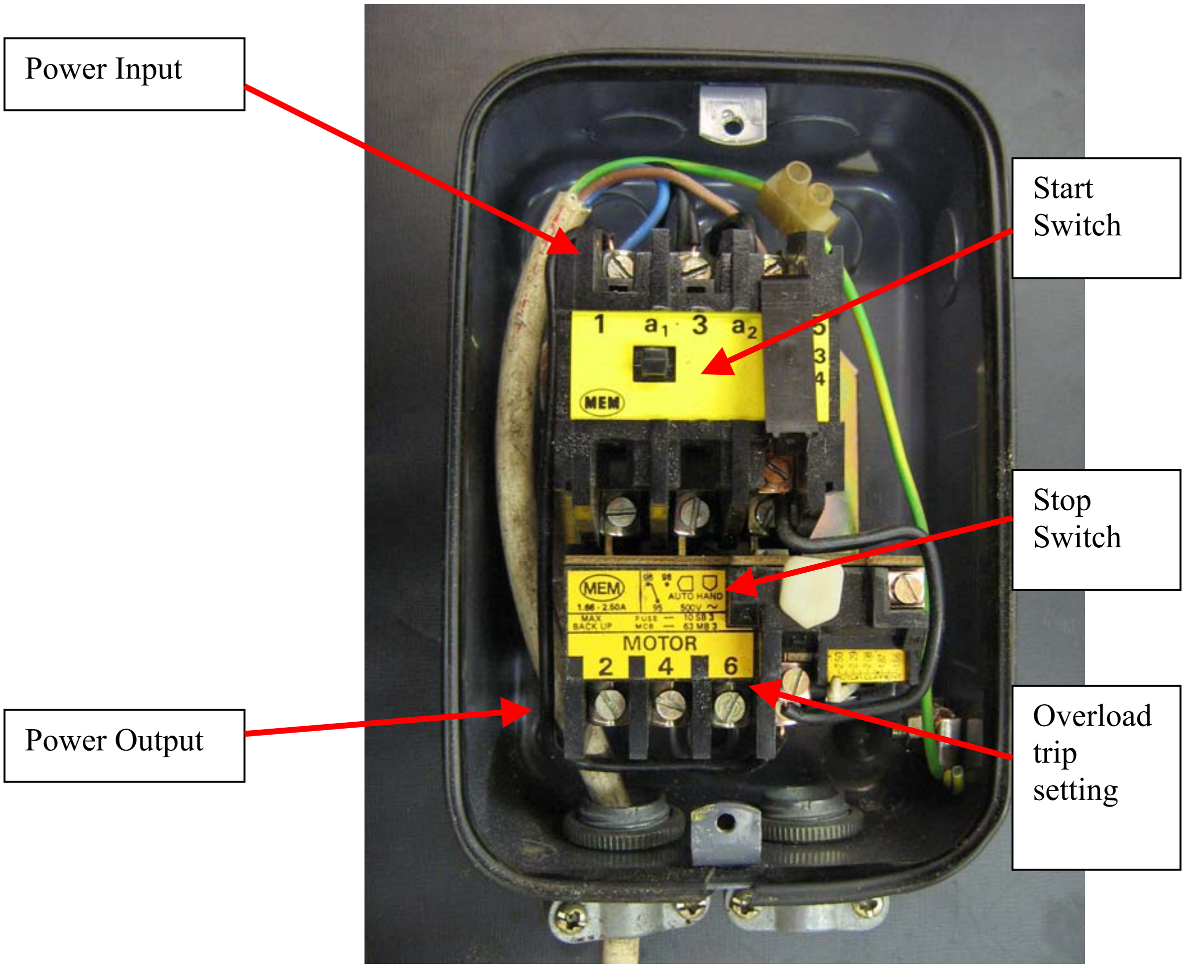


Fig 12 Inside view of older DOL starter

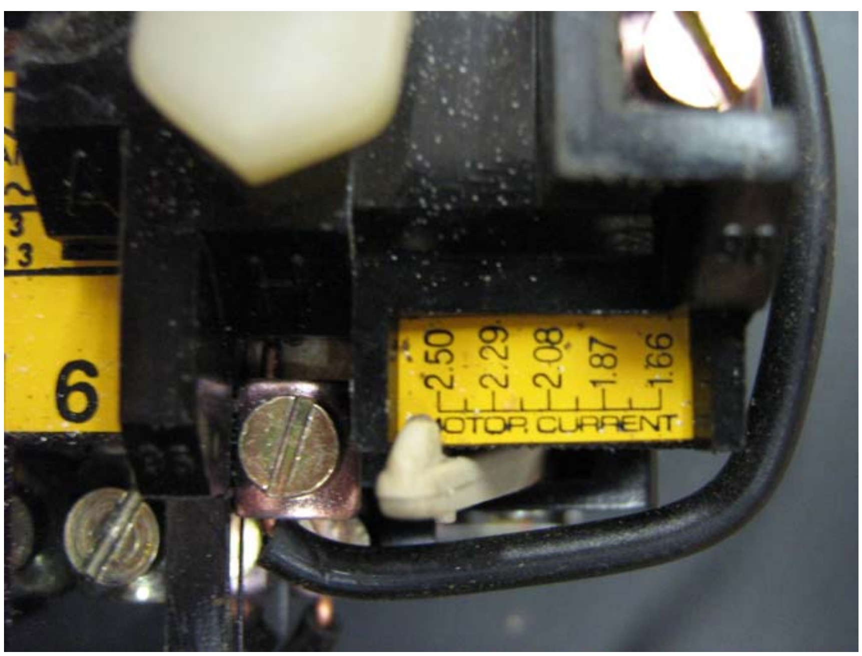


Figure 13 Close up of Overload setting control.

Note that at sometime the overload relay rating has been changed and does not agree with the data in Figure 11. Always check items that you have not bought brand new!

It is quite normal for manufacturers to supply small connection diagrams and sometimes even instructions inside the cover as shown in the next two pictures.

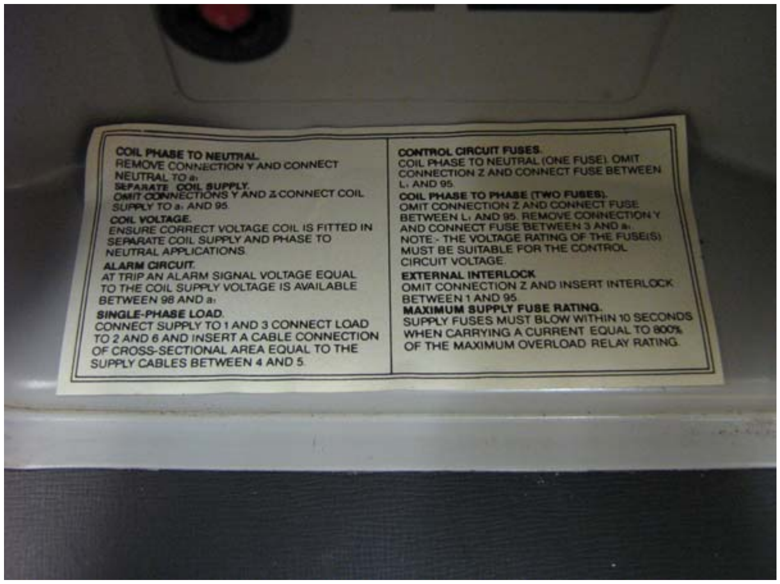


Figure 14 Instructions pasted inside the cover – Bonus!

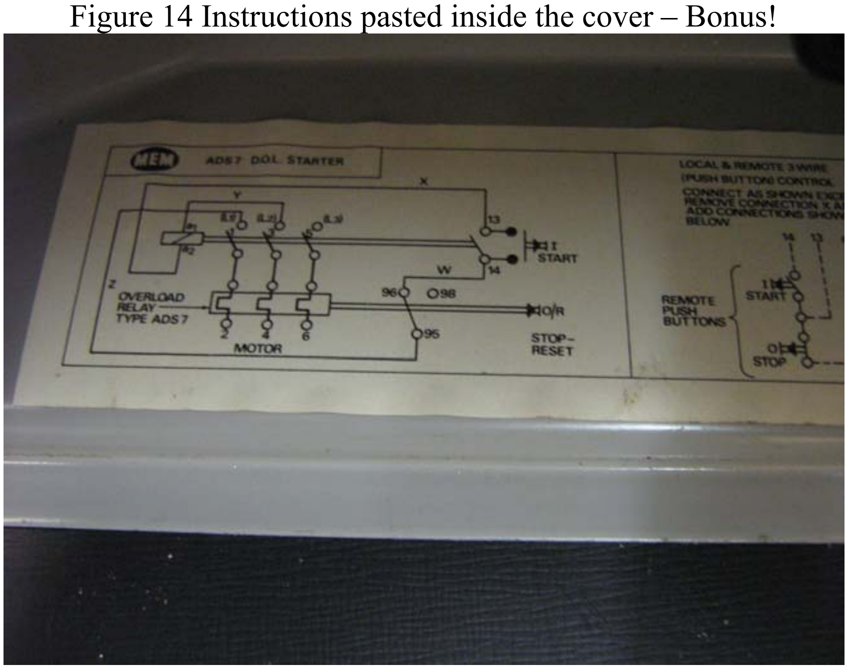


Figure 15 A Typical circuit diagram inside the DOL cover

The next couple of Figures show a more modern DOL starter as fitted to my table saw which has been single phase from birth.

Figure 16 & 17 Single Phase DOL starter that is still based on a three pole switch inside.

Very similar components to the older model but with rotary current setting instead of a lever. Modern units tend to be in a plastic enclosure.

Remote control of DOL starters

Most DOL starters can be operated by extra push buttons allowing the starter to be perhaps located nearer the motor and the control buttons close the operator. Furthermore an emergency stop switch can be located for foot operation on machines where both hand are normally busy supporting the work piece. Referring to figure 9*, extra start switches with **normally open (NO)** contacts may be wired in parallel with or replacing the existing start switch. Extra stop switches with **normally closed (NC)** contacts may be wired in series with or replacing the existing stop switch. Whilst these extra switches are only low current, they are still operating at the full supply voltage so attention needs to be paid to earthing any exposed metalwork and suitably protecting the cable path from the starter to the push button station.

Figure 9 shows a 3 phase starter but the principles for remote starting of single phase motors use the same principles. Ignore L3, consider L1 and L2 to be Live and Neutral.

There are some DOL starters that do not have a start switch as such and instead use a mechanical button to push the contactor closed after which the electromagnet holds the contactor in the normal way. The stop function is still provided electrically so extra stop switches can be added as above but adding remote start switches can be more difficult or impossible. Check that you have an appropriate starter before planning any changes to your controls

You may come across more complex starters where the control voltage is deliberately reduced with a transformer to 110v or even 24v ac on safety grounds. The contactor coils on these controls will be marked with the lower voltage and on no account should mains voltages be applied. In my experience, these lower voltage control systems are sometimes used on machines with multiple motors. The motors themselves work on normal voltages but somewhere in the control box will be a transformer, which is the clue to this type of arrangement.

Low Priced NVRs

With the drive for ever-lower manufacturing costs there are some NVRs coming on the market with slight different arrangements. It is now quite common for the start button to act mechanically onto the main power switch which saves a small amount of internal wiring and in some cases the stop button works similarly. There is nothing fundamentally wrong with this approach apart from removing the ability to have remote start and stop buttons that was always an option with the DOL starters shown above.

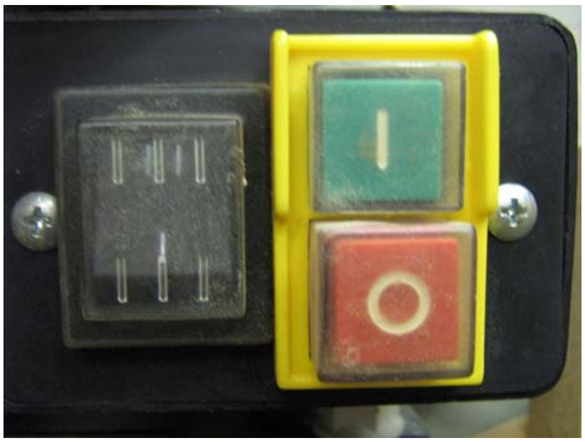



Figure 18 & 19 Some example low cost NVR switches

One possible drawback is that these NVRs can easily be confused with a simple switch such as shown in Figure 20 that has no NVR functionality.

Figure 20 – A simple switch – Not NVR!

The best way to check one of these switches is to operate the ON or Start button with the power switched off. A non-NVR switch will click and it is quite likely that the button will stay depressed. An NVR switch button will move but make little noise and return to its original position once you take your finger off.

Even with no motor connected a NVR or DOL starter will give a solid sounding clunk followed by a gentle buzzing sound. When you then turn the power off, there will be another clunk. Finally, when restoring the power, there will be no response, audible or electrical.

One important point to note it that these lower cost NVRs shown in Figures 18 & 19 do not include any thermal overload protection and hence the motor has much less protection against overload. Remember that fuses only protect wiring.
A 1kw motor running properly may draw say 1200 watts but the same motor overloaded may only draw an extra few hundred watts. Not enough to blow the fuse but the BIG difference is that that much more of the input power is being converted to heat and the motor can easily burn out.

I can only advise that larger motors above 1kW should be protected by a DOL starter.

Chapter 3 Running 3 Phase Machinery

This section will address the question that comes up regularly which is how to run 3 phase powered machinery in the home workshop. The attraction of such machinery is that almost without exception it is ruggedly designed and rated for trade use and often available from trade auctions, eBay, schools and colleges etc at reasonable prices. However, for purchasers without three phase supplies, the additional cost and hassle of some form of conversion to single phase operation has to be factored in when deciding how much of a bargain the item is.
Such machines are sometimes available with single phase motors already fitted but these tend to sell for high prices due to the convenience offered to the purchaser of being instantly ready to run after purchase.

It is not feasible for anyone to produce a set of universal instructions for single phase running. This document will set out the various options available and outline the pros and cons of each as seen by the author.

Option 1 Use 3 Phase Power

The first and most obvious way to power a 3 phase machine is clearly with 3 phase power. It will always be the best method involving no work on the machine and allowing it to run as designed. There is a big "but" to this approach and that is the potential cost.

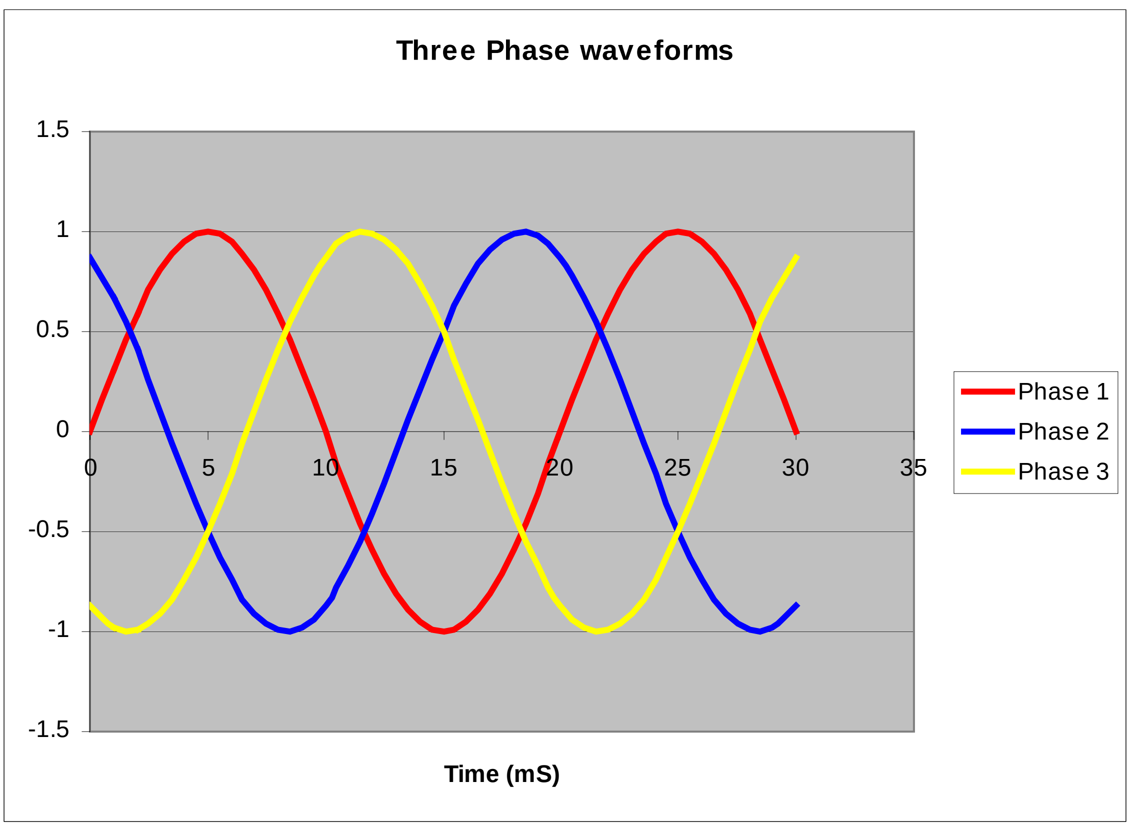


Figure 21 Three Phase Waveforms

All electricity is distributed in the UK as three phases. The grid runs at very high voltages gradually being stepped down with transformers until it arrives at your local substation at 11000volts between each phase. In an urban situation or relatively dense housing area this is a ground-mounted transformer somewhere along your road or perhaps the next one fenced off and emitting a low buzzing noise at 50Hz and harmonics of 50Hz. In rural areas the transformer is often mounted high on a pole or poles serving a relatively small number of customers. The transformer produces a local neutral nominally at earth potential and three phases each of which is a sinusoidal waveform with a mean (rms) voltage of 240 volts with respect to the neutral. Each phase is separated from its neighbour by one third of a cycle or120 degrees as shown in Figure 21.
If we look at the difference voltage between any two phases at the same point along the horizontal (time axis) we get a further set of three waveforms shown below.
The amplitude of these is √3 or 1.73 times greater than each phase. This means that the voltage between each phase is √3 x 240v = 415 volts.

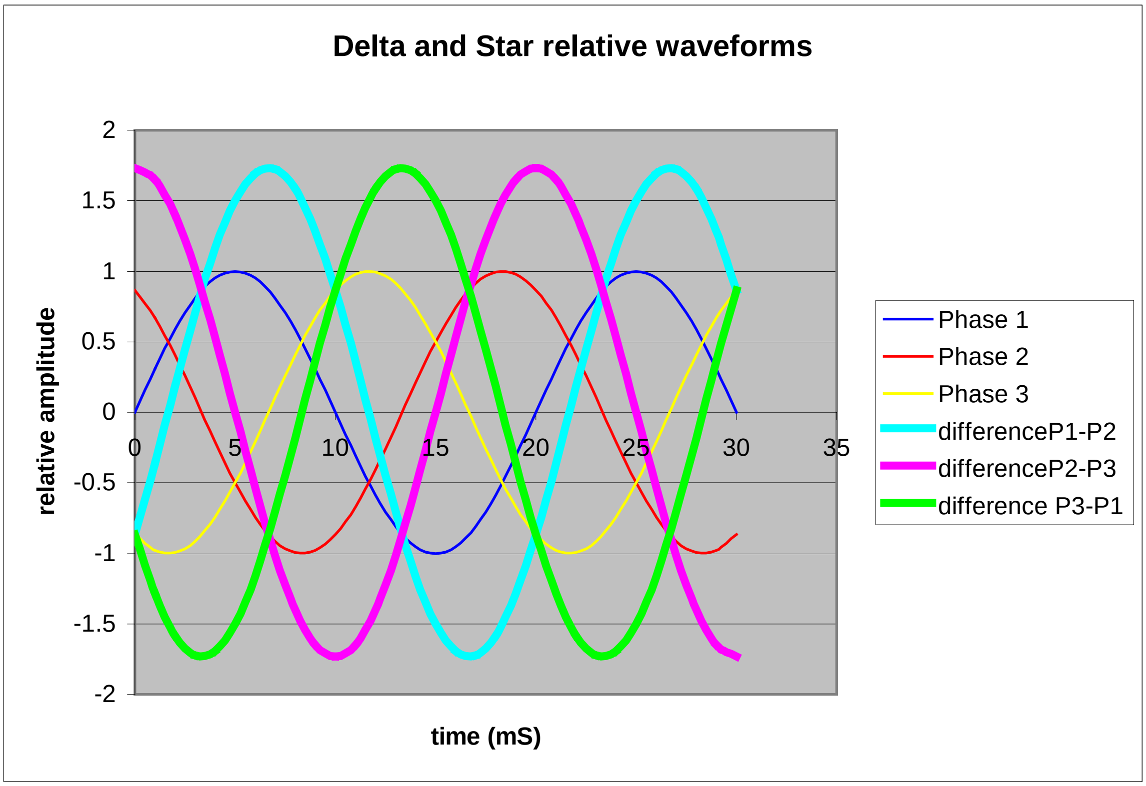


Figure 22 Three Phase Waveforms with Star Waveforms included

I shall not try and justify the forgoing paragraph here at the risk of losing yet more readers whose eyes may well have started to glaze over! This could be the subject of an annex in the future if there is sufficient interest.
However, a couple of familiar voltages namely 240 and 415 might be ringing a few bells as being the voltages associated with dual voltage, 3 phase motors discussed in section 1.

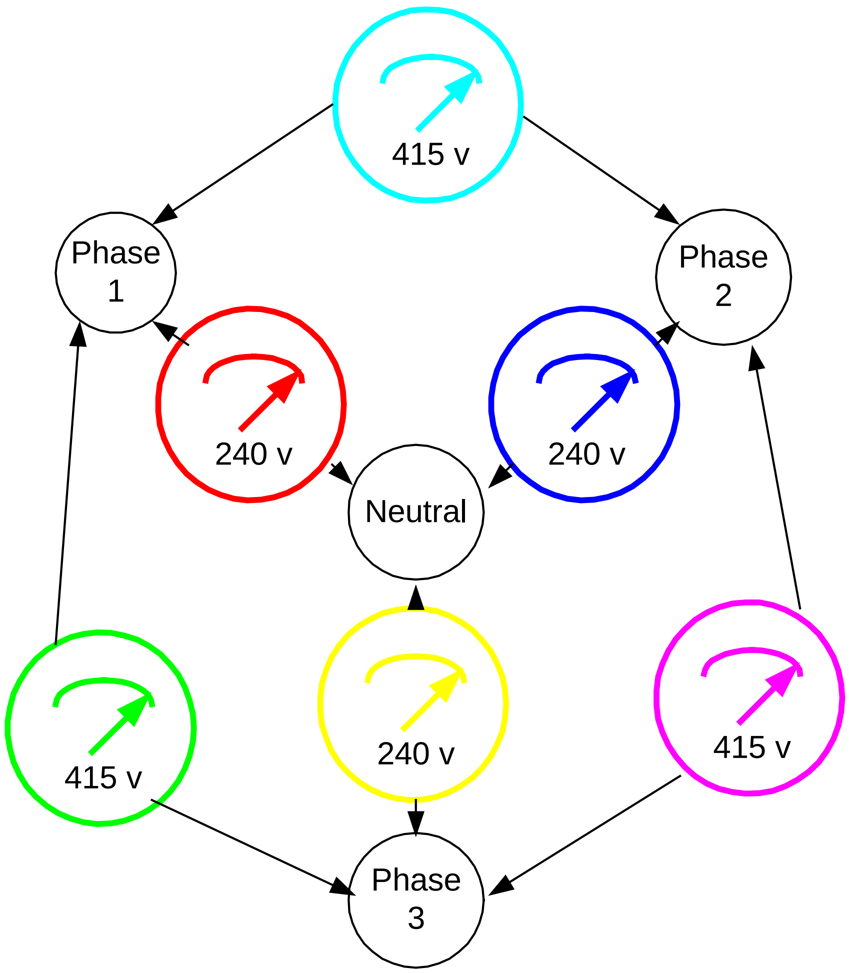


Figure 23 Diagrammatic Representation of 3 Phase Voltages

Domestic housing is normally supplied with one of the 240 volt phases and the neutral. In an attempt to balance up the load on each of the phases, each house in a row will be supplied with a different phase in turn.

Your local electricity service provider should be able to give you a quotation for the cost of providing all three phases to your property, providing extra fuses and exchanging your meter for a 3 phase one. This is likely to run into several thousand pounds. The further the distance of your workshop from a 3 phase supply will mean increased costs. You will need to provide a three phase distribution panel and suitable cabling to your workshop. As previously, the domestic consumer unit will be supplied from one of the incoming phases. All installation work will have to be done to appropriate standards and inspected before the electricity board will connect the supply. In practise this will almost certainly need to be performed by a professional electrician. A further continual cost impact will be that the annual standing charge will be higher and it is quite likely that the choice of tariffs normally available to domestic consumers will be much reduced possibly leading to high unit prices.

If your intention is to amass a selection of three phase machines and perhaps make extensive use of them for commercial gain then such cost may be perfectly acceptable and be amortised into the cost of running your enterprise. However I suspect for many of us with woodwork as a hobby albeit an obsessive one, these costs will be too high.

Creating a 3 Phase Supply

Ok if we have rejected the option of plumbing in a 3 phase supply, the next solution to consider is to create a three phase supply from our 240 volt single phase supply.
There are basically two commonly accepted methods of doing this one is to use a **converter** or an **inverter**. Sometime these terms are confused and used in error.
A converter is normally big and very heavy containing a big transformer and an inverter is a relatively lightweight, clever box of electronics.

Option 2 Single to Three Phase Converter

Commercially available converters usually contain two basic functions; firstly a step transformer to converter the incoming 240 volts into 415 volts and secondly various capacitors that are selected to match different power motors. The capacitor acts in combination with the motor windings to create an artificial third phase. This third phase is an approximation to that provided by true 3 phase supply and the accuracy varies with capacitor value and the motor. In order to start the motor, it is necessary to switch in extra capacitors to at least treble the capacitance during starting. This is a similar requirement to the single phase motor but we no longer have the ability to control the switch from a centrifugal switch in the motor as in the single phase case.
The starting arrangements vary with the design of the converter from providing a manual 'boost' button to having internal circuitry to do this automatically. Most converters will have a number of different settings that can be chosen to best match the motor. An ammeter is often provided and the setting is chosen to minimise the current consistent with smooth running of the motor. Setting the converter to too high a power setting usually means the motor will make a quite load humming/buzzing noise, which is to be avoided. This type of converter is described as a **static** converter.

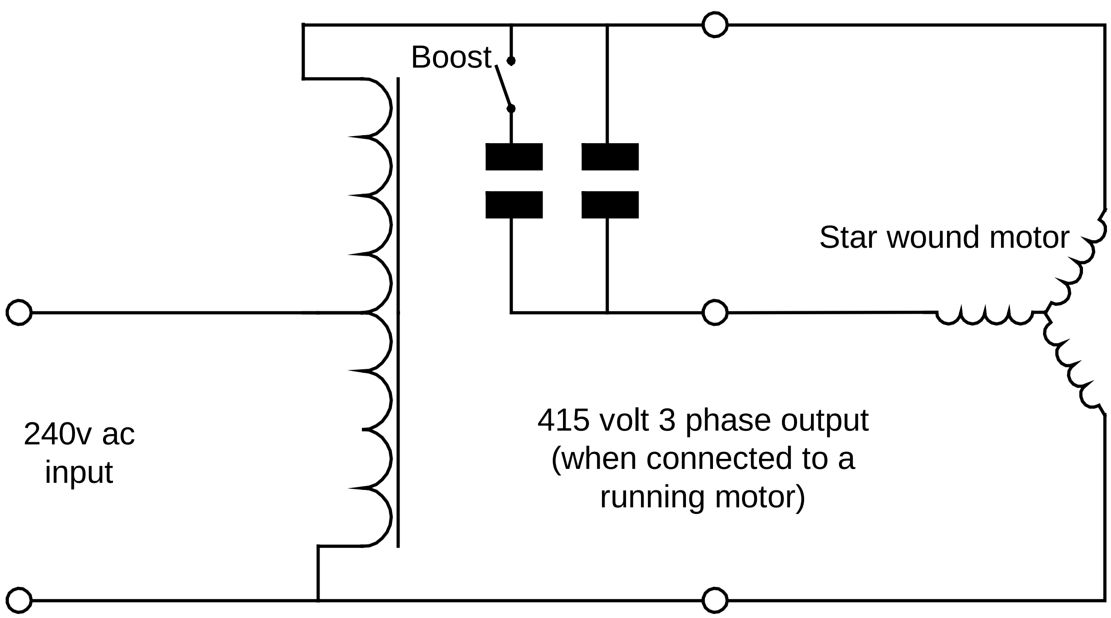


Figure 24 The Key Elements needed for a Basic Static Converter.

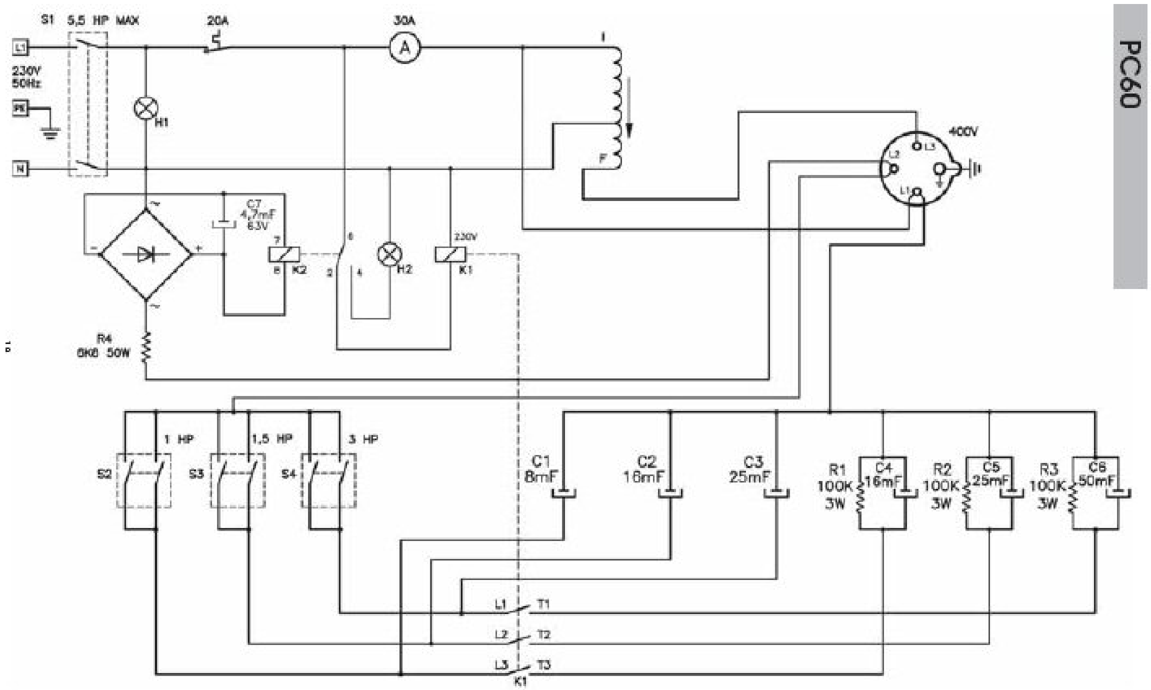


Figure 25 A Commercial Converter Circuit Diagram

Figure 25 shows the circuit of a commercial unit that offers seven power settings via 3 front panel switches and automatic starting.

In the last year or so I have noticed an automated controller that will automatically select the optimum capacitor value by switching multiple capacitors from an array of binary values eg 1, 2, 4, 8 etc. This is being sold as a “digital” unit which is somewhat stretching the definition of digital when compared to an inverter. The vendor sells the control module and a set of plans for the rest of the unit. I have not experimented with these.

Static converters are usually ideal for machines with one single speed motor where the power can be left set to the optimum setting and if a manual boost button is needed, the converter can be located close to the machine. They also make an easy solution to the older type single voltage star wound motors that can only be run from 415 volts.
A disadvantage of static converters is that depending how accurately they generate the third phase, the full rated output of the motor may not be achieved. This tends not to be too much of a problem with the older cast iron machines as they usually have generously rated motors and we are only using them intermittently so not working them too hard.

Another variant of the converter is known as a rotary converter. This is essentially a static converter integrated with a three phase motor, either inside or bolted on the outside of the case. The motor shaft is not connected to anything. The motor serves to provide an improved balance of the third phase and rotary converters almost always have automatic starting.

Rotary converters are ideal when used with several machines in a workshop (one at a time) especially when they have different power ratings as you don’t have to bother about setting them to suit each machine. They are also useful where a machine has more than one motor such as a spindle moulder with an auto feeder or a 4sided planer. Another big strength of the rotary converter is to run multiple speed motors. These have different windings for each speed (recall from chapter one that each speed needs different number of pole pairs) and so a static converter can struggle with pole switching motors.

The disadvantage of a rotary converter is they can be noisy especially when there is no load as they are often then running with too much capacitance at a time when there is nothing else making a noise in the workshop. A rotary converter is also a very heavy beast; not only does it have a large transformer rated at the maximum output but also a similarly rated motor.

I would imagine that a rotary converter built with one of the so called digital controllers mentioned above could be a nice compromise for a multi-machine/multi-speed set up.

I have only seen commercial converters operating with 415 volt output. There is nothing to stop the principle being used at 240 volts and it has the advantage of not needing a big transformer. I have built several 240volt units up to a couple of horsepower with very few components.

Option 3 Single to Three Phase Inverters

In my opinion these devices provide the ultimate solution to the generation of 3 near perfect 3 phase power waveforms whilst offering total control over the motor in terms of start up time, running speed and braking. Most also offer a great degree of protection to the motor windings. They are however only suited to running one motor at a time however a single unit can be used to run more than one motor by switching each onto the inverter one at a time. Most inverters are smart enough to measure the parameters of the motor they are connected to during start up.

Figure 26 A 1hp 240v inverter

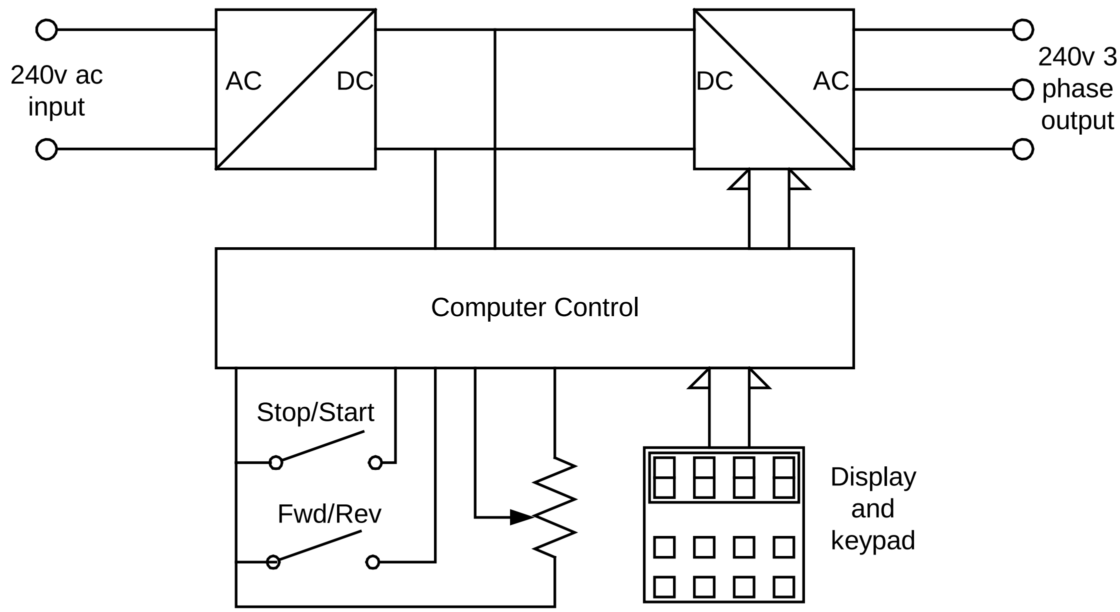


Figure 27A Basic Block diagram of an Inverter

Figure 27 shows the block diagram of an inverter. There are many degrees of sophistication but that is nearly always contained in the software. The incoming supply is converted to DC and under software control, three individual sine wave waveforms are generated at variable frequencies from typically 0.1Hz to 400Hz maybe even 650Hz. Most motors are not capable of running at these frequencies so a range might be from 10Hz to 100Hz for our uses. This means the motor will run between one fifth and double the design speed. All the controls shown on the lower section of Figure 27 are at low, safe voltages and isolated from the mains. Usually it is possible to program the control inputs to have different functions such as either as shown in the diagram or to make the two switches to be “start forwards” and “start reverse” and even programme what happens if both are pushed at the same time. The controls are very versatile indeed.

Figure 28 A TECO ½ hp inverter

However for many woodworking machines variable speed is not important and neither is running in reverse so all those controls are not needed and we can fit simple stop and start buttons. The inverter will take care of the NVR function and offers far more protection to the motor than any overload relay does. Provision should be made to be able to isolate the power to the inverter when the machine is not needed.

Inverters can also be programmed for different times to run up to speed and to slow down. They will accept instruction to do this is zero time (subject to the maximum current that you have also programmed in) but a practical setting for ramping up and down is possibly 2-3 seconds. External braking resistors can be fitted to give enhanced deceleration on machinery where there is a large rotating mass needing to be stopped quickly but this is a feature we are not likely to need often.

Figure 29 A 2hp 230volt inverter

Until relatively recently inverters have only been able to generate 3 phase outputs up to the same voltage level as the input voltage. Commercial inverters either work with a 415 volt input and generate 415 volt outputs or operate at 240 volts in and out as in the diagram. Therefore, it has not been possible to run a 415 volt motor from a 240 volt input. This is still largely the case but there have been two developments.

Firstly, some traders have been taking 415 volt units and modifying the input rectifiers to step up the voltage and selling those without necessarily stating that they have been modified. Also one or two manufacturers are recognising the gap in the market and are starting to design units to step up the voltage. Both of these newer types are being sold at premium prices.

With the current state of the market I believe the best option is to stay with 240 in – 240 out inverters and use these with dual voltage motors configured in Delta mode. However one of these voltage-converting inverters may well provide an economic solution to a machine with a fixed star wound 415 volt motor.

Figure 30 A Mitsubishi 1hp Inverter used on my bandsaw.

You may also read on traders websites who don't offer voltage converting inverters about how the modified ones are not CE marked which whilst being true, as far as current law goes at least, we are not required to have only CE marked equipment in our home workshops. This may be different if you are running a business and employing staff. Best to check. However, I believe their main objective is to try and put purchasers off doing business with their competitors!

Are all inverters born equal?

No is the simple answer. In addition to voltage and power ratings, some have no displays or buttons on the front and are slightly lower priced as a result. These are designed for remote operation and need a Basic Operator Panel or BOP to set them up. In some cases they have a serial port RS232/485 or USB to set them up from a laptop with software you can download from the manufacturers. Once set up you don't need the laptop or BOP although the BOP can provide convenient stop and start buttons.

Figure 31 A Siemens BOP fitted on a front panel

It is not unusual to see units only protected to IP 20 (see annex B) so it is important to install these in dry and relatively dust proof locations. Some older ones are fan cooled and so some airflow is necessary. More modern units are extremely efficient (97%) and can control kilowatts and only just get warm themselves.

Some units can cause a whine from the motor as the switching frequencies involved in generating the outputs are in the audible frequency range and within the resonant frequencies of the motor structure. Most of the application using the motors rated speeds or higher will create enough noise to drown this out but if you have an application where low motor speeds are in use then this might be an annoyance. Most but not all inverters have the ability to programme the switching frequencies in a few steps and some cases up to say 16kHz. which is both above most of our hearing range and above the resonant frequencies of the motor. Running at the higher frequencies can reduce the efficiency slightly but the maximum power out can be reduced again by programming to compensate. However, for ‘domestic’ duty levels I don’t bother with this. The inverters are all thermally protected anyway.

The switching action used by all inverters can cause some interference at radio frequencies. Some have integral filters and others can be used with external filters. In practise I have found this to cause very little trouble and can operate a VHF radio in the workshop without interference. I also run Ethernet computer networks over the mains cabling using Homeplug and notice no data dropouts.

Option 4 Motor Changing

The final option for converting a machine to single phase operation is to fit a single phase motor. The relative attraction of doing this compared to the electrical solutions above depends on a number of factors including:-

- Price and availability of a suitable single phase motor
- Mechanical considerations
  - Motor mounting
  - Shaft mounting
  - Overall dimensions

The electrical considerations of a motor swap are fairly minor and in virtually every case, the DOL starter switch will need to be replaced to offer both 240volt operation and a higher rating of overload relay consistent with the greater current that will be drawn by a motor of equivalent power to the original one.

Standard Motor Mechanical Specifications

The key dimensions for electric motors have been governed by British Standards for many years however the standards have changed over the years so unless the machine is relatively modern, fitting a modern motor to an older machine will involve varying degrees of modification to the mounting arrangements and to the drive arrangements Usually the motor drives a pulley with a belt or belts and the motor mounting is adjusted to have the correct tension in the belt to transmit the power to the machine. Virtually all the motors we are likely to come up against will be mounted in one of three ways.

- Foot mounted
- Flange mounted
- Face mounted

A foot mounted motor will either have a couple of feet cast into the housing or more commonly now, 2 feet each with 2 bolt holes, attached to the main body by bolts. Usually this offers different radial positions of the electrical connection box and body mounted capacitors relative to the mounting plane.

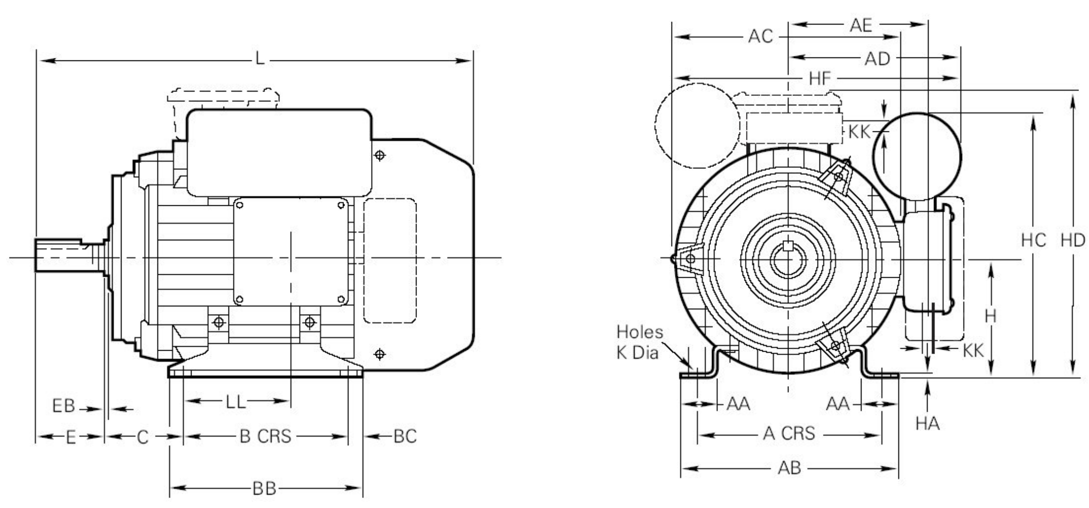


Figure 32 A Foot Mounted Motor - B3

The foot mount will have 4 bolt holes of diameter K on a footprint A x B and with a distance C between the inboard end of the shaft and the nearest mounting holes at the shaft end.

Modern motors are built on standard Frame Sizes. The frame size is readily measured on foot mounted motor and is the height in millimetres of the centre of the shaft above the mounting plane – shown as H in the right hand drawing of Figure 32.

This foot mounting arrangement is referred to as B3, so you might see in a motor catalogue an 80 frame B3 mount motor 0.75kW 4 pole which more or less defines the key parameters of the motor.

Motor length does also vary. As the motor power increases the frame gets longer in typically 2-3 steps and then the next motor up in the range goes up a frame size and reduces in length. The relationship between motor power, frame size and length is up to the manufacturer. The actual dimensions can be found in the manufacturers catalogues.

Frame size	Motor power kW	Horsepower
63	0.12-0.25	1/6-1/3
71	0.25-0.37	1/3-1/2
80	0.55-0.75	3/4-1
90	1.1-3.0	1.5-4
100	3.0-4.0	4-5

Table 4 Typical relationships between frame sizes and motor power.

Some of the power ratings overlap in the table. As the number of poles increase there is more wire to fit in the windings so in some cases the frame size of a 4 pole motor will be bigger than the same power 2 pole motor.

	General																	
Type	A	B	C	H	K	L	LL	AA	AB	AC	AD	AE	BB	BC	HA	HC	HF	KK
63S	100	80	40	63	7	207	74	19	119	126	127	-	100	10	2	169	190	20
71M	112	90	45	71	7	238	116.5	19	131	140	126	95.5	110	10	2	197	165.5	20
80M	125	100	50	80	10	278	75	27	157	160	145	102	127	13.5	4	208	224	20
90S	140	100	56	90	10	322	100	28	164	178	153	110	150	13.5	4	218	242	20
90L	140	125	56	90	10	322	100	28	164	178	153	110	150	13.5	4	218	242	20
100L	160	140	63	100	12	368	117	28	184	208	125	120	170	15	4	250	-	20

Table 5 Motor dimensions: Foot Mount and common body measurements

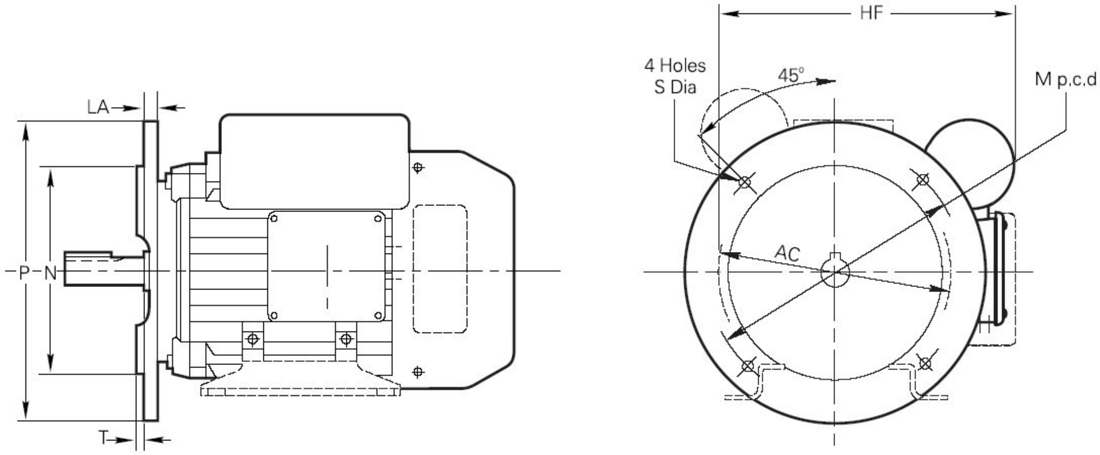


Figure 33 Flange mounted motor B5 (B3/B5 or B35)

The Flange mounted motor is shown in Figure 33. The main method of mount this motor is using the 4 plain (non threaded) holes S mm diameter on a p.c.d. of M mm. P.c.d. simply stand for Pitch Circle Diameter and means equally spaced holes lying on a circle of given diameter M.

The flange is always larger than the main body of the motor although the electrical connection box and capacitors may lie outside the flange diameter. The concept of Frame Size is still used with flange motors but is no longer readily measured. A flange mount is known as B5. Just to add to the potential confusion, some flange mount motors have feet fitted. Whilst this does facilitate the measurement of frame size, quite often the feet are not easy to use as the flange can get in the way of some foot mounting arrangements. These motors are sometimes referred to as B3/B5 or B35.

The third common mounting method is face mount as shown in Figure 34

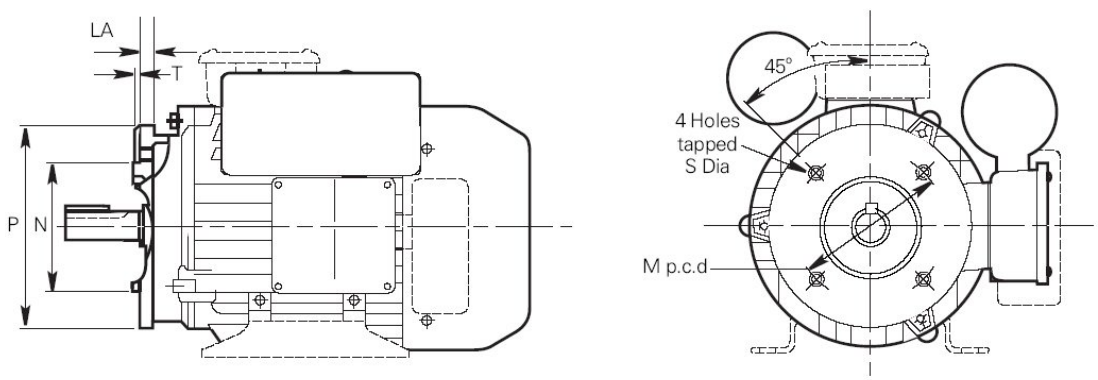


Figure 34 A face mounted motor B14 (B3/B14 or B34)

Similar to the flange mount motor the face mount also has four holes on a circle but in this case they are blind female holes tapped with metric threads into the face of the motor and lie on a much smaller circle than the same frame sized flange mount. This is referred to as B14 and can also be combined with foot mounting when they are known as B3/B14 or B34.

Type	IM B5 mounting						IM B14 mounting					
	M	N	P	S	T	LA	M	N	P	S	T	LA
63S	115	95	140	10	3	7	75	60	90	M5	2.5	7
71M	130	110	160	10	3.5	7	85	70	105	M6	2.5	9
80M	165	130	200	12	3.5	12	100	80	120	M6	3	9
90S	165	130	200	12	3.5	10	115	95	140	M8	3	9
90L	165	130	200	12	3.5	10	115	95	140	M8	3	9
100L	215	180	250	15	4	11	130	110	160	M8	3.5	22

Table 6 Flange and Face mounting dimensions

Shaft sizes

Shaft sizes are linked to the motor frame size. Pulleys are retained by allen grub screws (or more correctly setscrews) and the torque is transmitted by a steel key. The correct sized key must be used and the screws tighten firmly. Loose keys will 'fret' leading to both the keyway in the shaft and the pulley becoming enlarged and wrecking both components. Some pulleys are additionally retained by a large washer and a bolt screwed into the end of the shaft. Often these can be left-hand threads so when trying to undo one that seems reluctant to shift, try turning it the other way before getting tough with it!

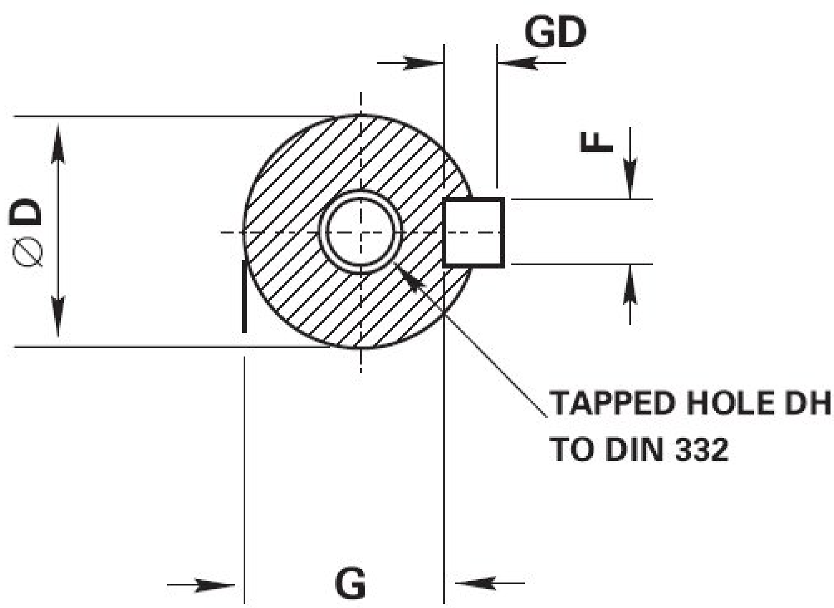


Figure 35 Standard Shaft Dimensions

Type	Shaft D	E	F	G	GD	EB	DH
63S	11	23	4	8.5	4	1.5	M4 x 10
71M	14	30	5	11	5	6.5	M5 x 12.5
80M	19	40	6	15.5	6	1.5	M6 x 16
90S/L	24	50	8	20	7	1.5	M8 x 19
100L	28	60	8	23.9	7	1.5	M10 x 22

Table 7 Standard Shaft Dimensions

Fitting a modern motor to a pulley from an older machine is almost certainly going to mean either boring out the pulley to fit a larger shaft or making a sleeve to effectively reduce the bore. The keyway will almost certainly need modifying.

These operations are not difficult if you have access to metalworking machinery –particularly a lathe and a method of cutting a keyway. It is vital that the boring operations modify the bore to be concentric with the original. Any eccentricity or run-out will lead to belt vibrations at the shaft speed which could easily transfer to the saw blade, planer knives etc.
Often when pulleys are made the only machining that is done is the bore and the Vs that the belt runs in. My top tip on the lathe is to turn some scrap steel to be a good fit in the original bore. Mount the pulley and machine a reference surface concentric with the original bore. This can then be use to check the concentricity of the pulley in the chuck before modifying the bore.

Motor mounting conversions

Foot mounted motor swapping can often mean little more than drilling some new hole to suit the new foot hole positions or sometime an adaptor plate can be useful. However this may shorten the distance between the pulley centres and the belt can no longer be tensioned. In this case use of a shorter belt can be helpful.
Flange and face mount motors can also be mounted by drilling new holes even if the difference in p.c.d is small and the holes would overlap, usually the motor can be rotated by 10-15 degrees and new holes drilled.
If this is not possible for some reason, it can help to use a circular adaptor plate. For example when replacing a flange mount motor, use a face mount motor and fit on your own flange to suit the original mountings. This will cost maybe 10mm off the shaft length but this is often acceptable.

Annex A: INSULATION CLASSES

Often abbreviated "INSUL CLASS" on nameplates, it is an industry standard classification of the thermal tolerance of the motor winding. This is determined by the ambient temperature, the heat generated at fully loaded conditions (temperature rise), and any hot-spots in the motor insulation. Insulation materials are classified as A, B, E, F, and H. The letter designation indicates the thermal tolerance, or winding's ability to survive a specified operating temperature for a specified period of time. The classes are based on **adding** the ambient temperature and the operational heat created by the motor. They are shown below.

20,000 Hour Life

Class	Max Temp rise (by resistance, ^{o} C)	Average Temp. @ 40^{o} C ambient	Limiting hot-spot temperature (^{o} C)
A	60	100	105
E	*75*	*115*	*120*
B	80	120	130
F	100	140	155
H	125	165	180

Insulation classes are *generally* arranged in ascending alphabetical order: for example, class F insulation has a longer nominal life at a given operating temperature than class E, or for a given life it can survive higher temperatures.

Annex B: Enclosure IEC IP ratings

Enclosure designations
Like NEMA in the US, IEC has designations indicating the protection provided by a motor's enclosure. However, where NEMA designations are in words, such as Open Drip Proof or Totally Enclosed Fan Cooled, the IEC uses a two-digit "Index of Protection" code to describe how well the enclosure protects the motor from the environment. The first digit indicates how well protected the motor is against the entry of solid objects, the second digit refers to water entry. The two digit number is followed by letters "IP".
Here's what the first digit means:
0 - No protection
1 - Protection against objects larger than 50mm (about 2 in.) in diameter, like hands
2 - Protection against objects larger than 12mm (about 1/2 in.) in diameter, like fingers
4 - Protection against objects larger than 1mm (about 0.04 in.) in diameter, like small tools and wires
5 - Complete protection, including dust-tightness.

The second digit signifies protection against water entry. Here are those ratings:
0 - No protection
1 - Protected from water falling straight down
2 - Protected from water falling as much as 15 deg from vertical
3 - Protected from spraying water as much as 60 deg from the vertical
4 - Protected from splashing water coming from any direction
5 - Protected against jets of water from all directions
6 - Protected from heavy seas
7 - Protected against the effects of immersion to depths of between 0.15 and 1.0m
8 - Protected against the effects of prolonged immersion at depth

For most industrial application, an IP 22 relates to open drip-proof motors, IP44 or IP54 to totally enclosed, IP45 to weatherproof, and IP55 to 'washdown-duty' motors.

Annex C: Motor Duty ratings

S1 duty cycle

Continuous duty. The motor is capable of operating at the stated load continuously.

S2 duty cycle

Short term duty, expressed in terms of a time period. The motor is capable of operating at the stated load for the time period stated, and then should be allowed to fully cool before further operation.

S3 duty cycle

Intermittent periodic duty with short on-off cycles, expressed in terms of a percentage. The motor is capable of operating at the rated load for the percentage of time stated. The remainder of the time it must be stationary and not powered.

For non-continuous operation, the period over which the duty cycle is defined may be specified by the manufacturer or if not specified is assumed to be 10 minutes.

Annex D: Induction Motor Efficiency

Note: the table below shows typical efficiencies for older motors when run at 75 to 100% of rated load: there is currently an international focus on improving the efficiency of electrical machines, and you will now see motors advertised as “high-efficiency” or IE2 etc.

Power (hp)	Efficiency (%)*			
	(kW)	Single-phase	Single-phase (cap. run)	3-phase
0.5	0.37	64	67	70
1	0.75	68	73	76
2	1.5	72	78	81
3	2.2	74	79	83
4	3	76	80	84

** Note: low-cost motors manufactured in the far east can have significantly lower efficiencies than those shown above.*

New International Efficiency (IE) Class	Efficiency Level	Comparison
IE1	Standard efficiency	Efficiency levels comparable to the existing EFF2 in Europe
IE2	High efficiency	Efficiency levels comparable to the existing EFF1 in Europe and identical to the U.S. EPAct for 60 Hz
IE3	Premium efficiency	New efficiency class in Europe and identical to NEMA Premium® in the United States for 60 Hz

The standard also reserves an IE4 class (Super Premium Efficiency) for the future. The following motors are excluded from the new efficiency standard:

* Motors made solely for inverter operation
* Motors completely integrated into a machine (pump, fan or compressor) that cannot be tested separately from the machine.

Annex E: Harmonisation of Mains Supply Voltage

Traditionally in the UK we have referred to mains voltages as being 240v and sometimes 230v with their associated 3 phase voltages of 415vand 400v.
Majority of the motors and starters we will come across will be marked with these voltages and for this reason I have used them in the text.

However for some years mains supply voltages have been harmonised across Europe as 230v or 400v +10%/-6%. This does not mean we get any different voltages delivered to our homes & workshops; it is just that the tolerances have been set wide enough to accommodate the existing voltages.
Applying the worst case tolerances we get a range of 216v to 253v for single phase supplies and 375v to 438v for phase to phase voltages.

Hope fully this may help to explain voltage measurements that you may make from time to time.

Annex F: Electronic switching of starter winding in single phase motors.

For tens of years, single phase motors have use a centrifugal switch mounted inside or on the end of the motor casing to control the starting process. The contacts are closed when the motor is stationary and when a predetermined speed has been obtained a pair of weights move outwards and open the contacts. This state in maintained all the time the motor is running. When the motor is switched off and slows down the contacts close usually with a clicking sound and subsequent slight rubbing noise until the motor stops turning. Sometimes these noises cannot be heard over the noise made by the machine that is being driven by the motor.

Recently at least one manufacturer, ABB, have introduced a range of motors they call CSR which use an electronic module to switch the starter winding.

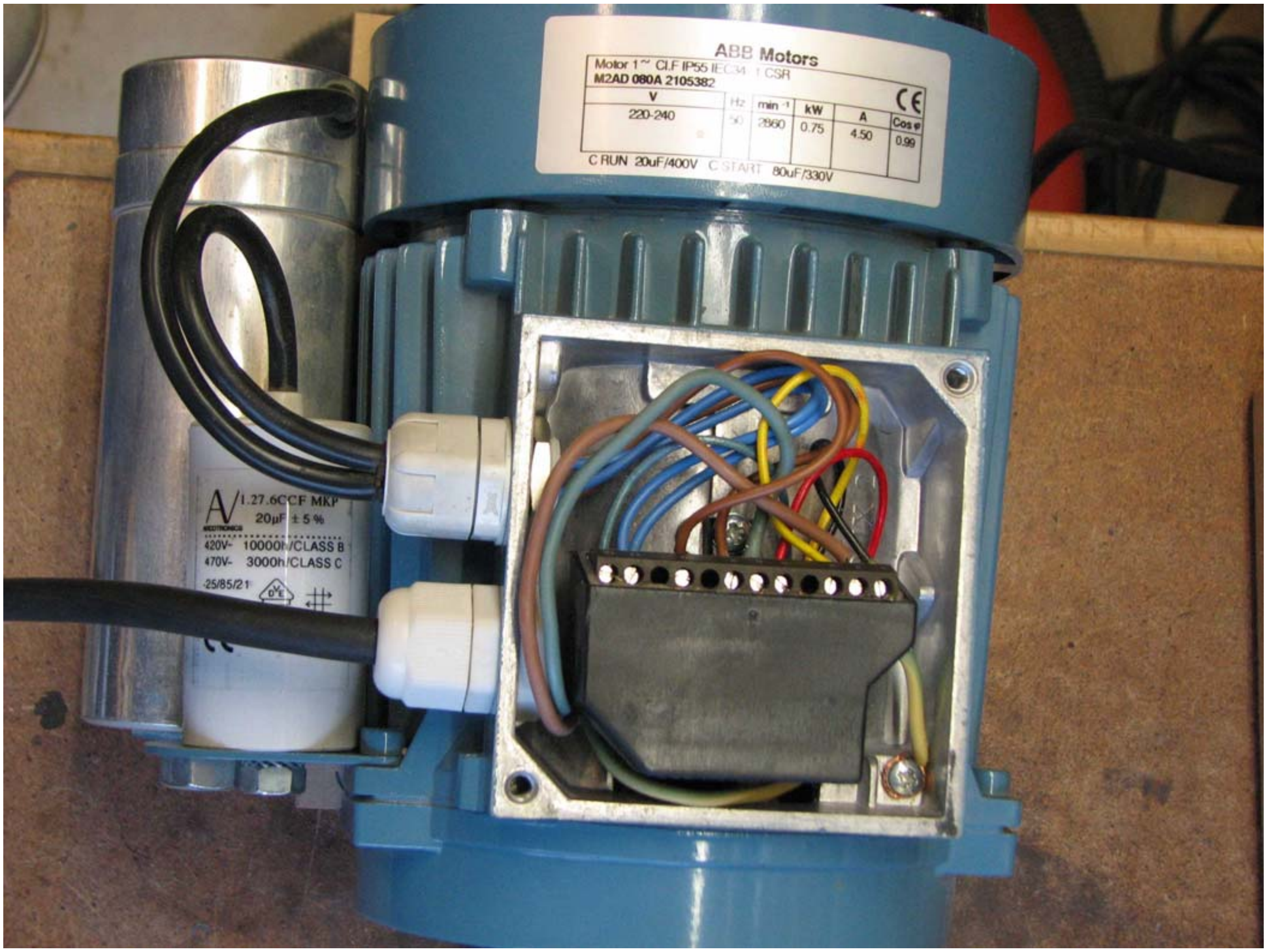


Figure F1 An ABB CSR motor

This motor happens to have both a run and start capacitor but inside the terminal box, the new electronic module moulded in black plastic can be seen. Figure F2 shows the connections to the module.
The diagram shows the symbol for an AC electronic switch known as a TRIAC connected between terminal 6 and 9.

This is diagrammatic form of a fairly sophisticated switch. According to the manufacturer, the switch senses when the motor has achieved the nominal speed (see Table 2) and switch out the starter winding.

Additionally to protect the starter winding, irrespective of the motor speed, the switch will disconnect the winding after 2 seconds.

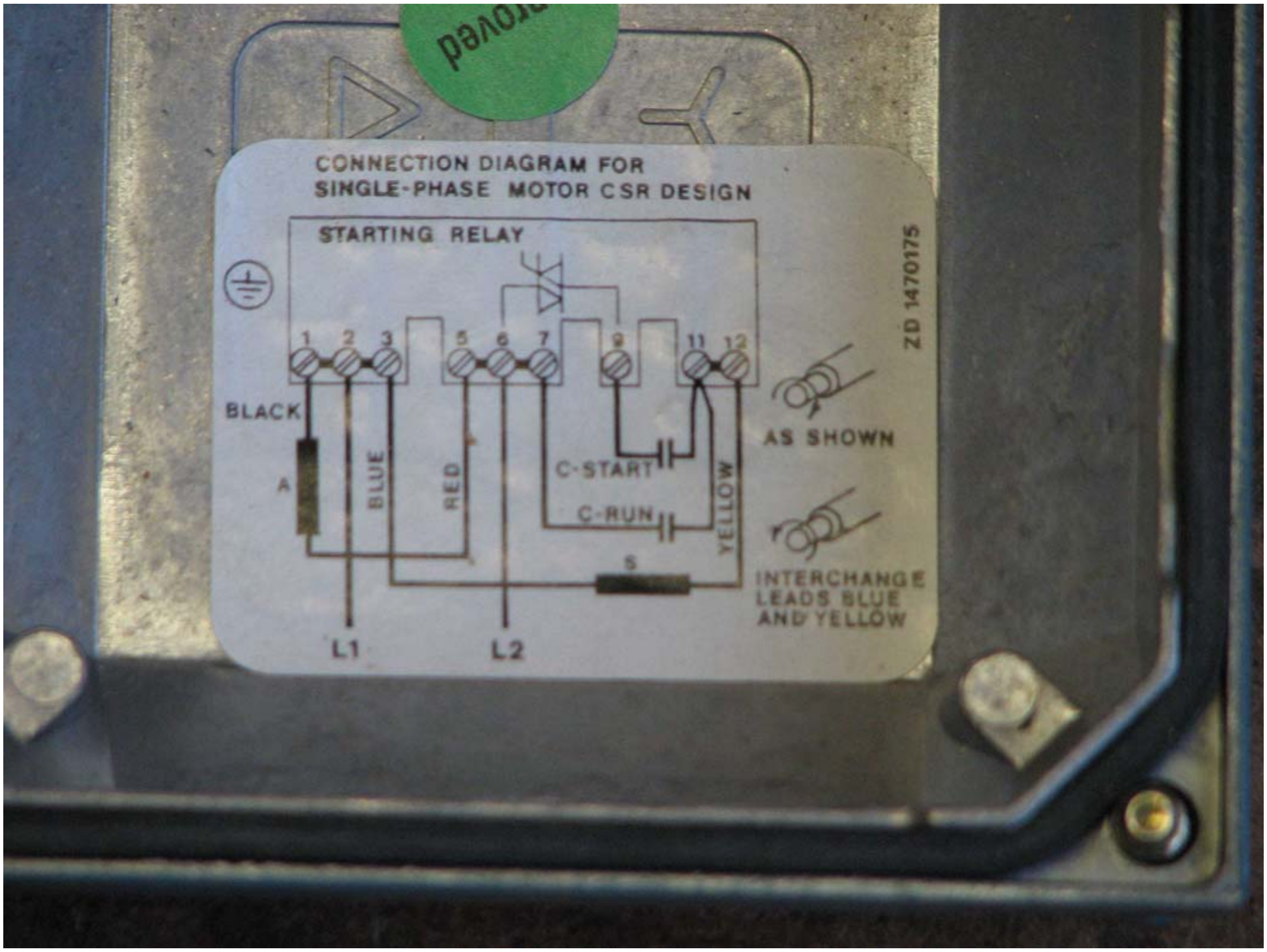


Figure F2 Connection diagram

Herein lies a potential problem with this type of motor. If for some reason, the motor load ie the machine it is driving, does not get up to speed in under 2 seconds, the start winding is switched off and the motor runs below design speed which in turn leads to excessive current in the running winding. Provided the motor is connected via a suitably rated NVR with overload protection, the NVR should trip and the motor is protected.

In a recent case of a motor driving a planer which had a older style heavy cutter block, the starting torque of the motor could not accelerate the cutter block to the correct speed within the 2 second timeout. Furthermore, the motor was not protected by an overload trip and started smoking and could well have burnt out if the user had not unplugged it quickly.
Interestingly the original machine was designed for a ½ HP motor but with a traditional centrifugal starting switch. The new CSR motor was rated at 1 HP and yet could not start the machine adequately. The manufacturer stated that the 2 second timeout could not be adjusted and so could offer no solution to this problem.

It is not known if other manufacturers will introduce these electronic starters but it is reasonable to assume that they will become more popular with designers as the mechanical switches can be done away with in favour of a potentially cheaper and more reliable electronic module.

When changing a motor on a machine with high inertia rotating parts – typically a large older style planer, serious consideration should be given before fitting a motor with electronic control especially if you are parting with hard earned cash for the motor.

I am indebted to Graeme Durant for bringing this problem to my attention and also providing the photographs of the ABB motor.

Annex G: Series Parallel Starters

I have recently come across an English Electric 3hp motor that is thought to date from the 1930s. Initial information was via email and mentioned 5 power cables going between a large starter control box and the motor and none were an earth connection, which was separate.
This was outside my experience and also of that of colleagues older than me. A mystery needed solving!

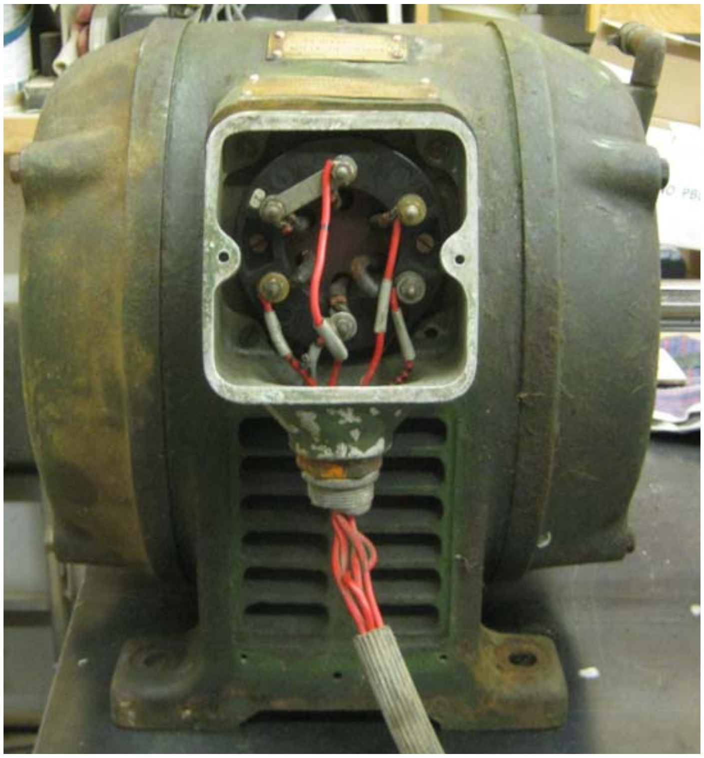


Figure G1 The English Electric motor

Figure G2 Motor rating plate

Just to be helpful all wires were red and disappeared off to the control box down a short length of garden hose! The motor is incredibly heavy 98kg according to my bathroom scales

The control box was made by AEI and branded STAYRITE

Figure G3 AEI STAYRITE label

Figure G4 Control box exterior

This is the external view. I think the covered aperture was for an optional ammeter.

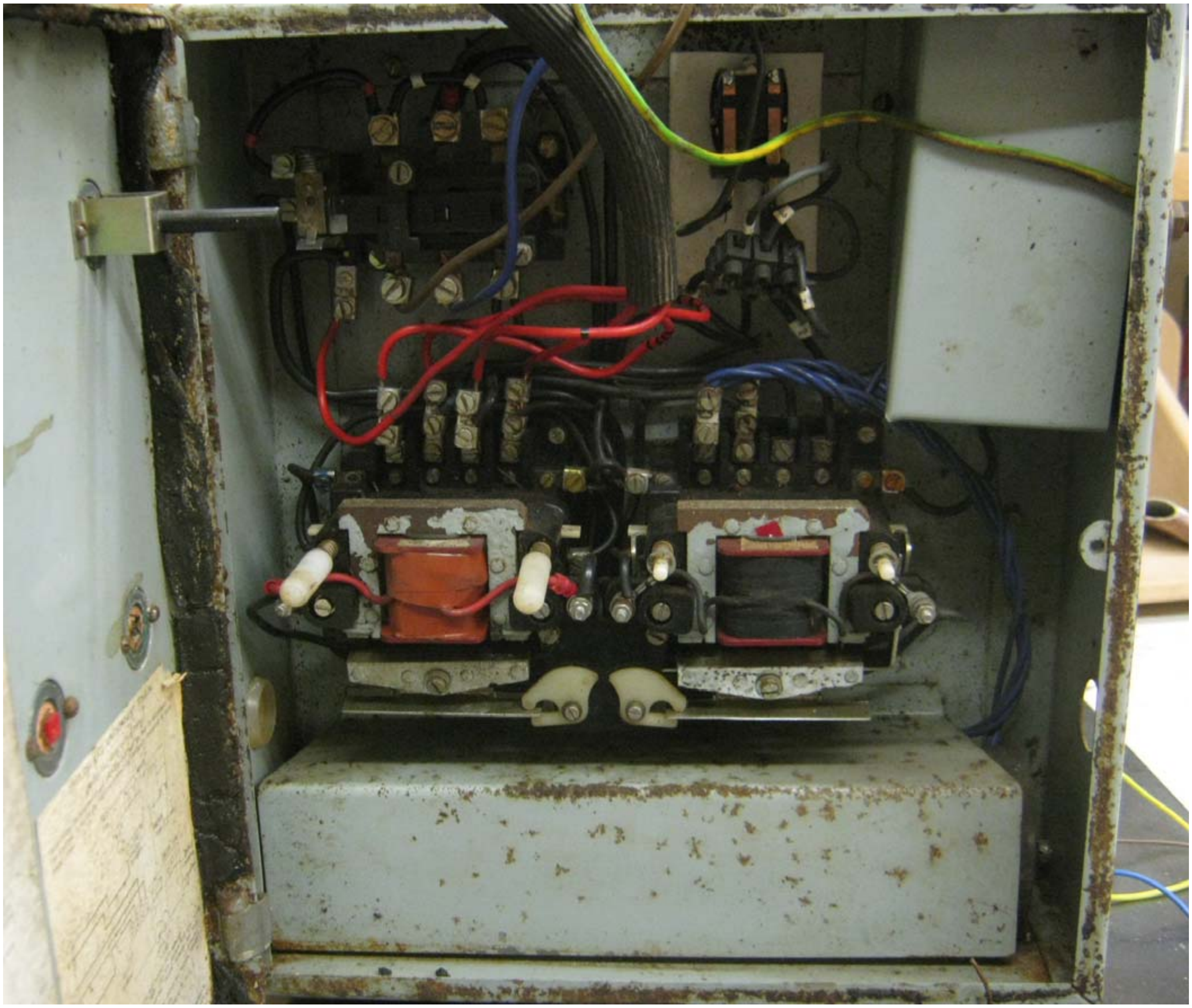


Figure G5 – inside the control box

This is the inside view of the control box. It contains two interlocked contactor ensuring that only one could operate at a time, a thermal overload trip device, three paralleled capacitors totalling 235 microfarads and a relay, which was clearly much newer, and almost certainly a replacement for an original defective part.

The three capacitors are behind the metal shields at the bottom and top right. The two white cylinders on the left hand (Run) contactor are the Start (left) and Stop (right) switch actuators controlled by the buttons on the front. Projecting black rod top left acts directly on the thermal overload trip to reset it.

The new owner of the motor had said there was a history of it blowing fuses. Given the number of unknowns, I thought there was no point in just wiring it up and blowing more fuses so I opted for a more analytical method. I prepared three mains voltage standard filament light bulbs with lengths of wire soldered onto their terminals, one to substitute for each of the windings. Having connected these to where the motor wires would normally go, I applied a power to the controller.
When I pressed start, the two run lamps glowed dimly and the starter lamp came on at full brightness.
When I left go of the start button, the start lamp went out and the two run lamps lit at full brilliance.
When I pressed stop all the lamps went out.

So that told me that
a) The controller was basically working
b) The starting capacitors were passing current (they could still be short circuit though!)
c) The run windings were switched in series during starting (hence the dimmed lamps)
d) The run windings were switched to parallel during running
e) The stop function was also working

All this from adding a few light bulbs!

Measurements on the capacitors indicated 235 microfarads and no appreciable leakage current at DC so all looking good on the controller front.

Next I turned my attention to the motor. Measuring the DC resistance of the run windings I got equal reading of 1.5 ohms on each and 3.5 ohms on the starter winding. The run windings seemed a bit low to me for a 3 hp motor but this is a very old design and things could well have been done differently then. For comparison, the run winding of a 1990s motor is about 1.7 ohms in total where as these two windings in parallel would measure 0.75 ohms. It certainly explains the need to connect in series during starting to keep the current down to manageable proportions.

The most likely problem on an old motor and one that had been stored in a damp shed is leakage from any of the windings to the case. A lot of insulation in those days was cotton and this would absorb moisture. Add years of collected dirt which would also hold moisture and there is a likely leakage path to earth.

Insulation leakage meters made to measure this do exist but as not everyone has one, I chose to describe an empirical method. This method is not for the faint hearted but undertake with care in a dry environment and using the rule of always keeping one hand in your pocket, there is little risk.

My dc resistance meter did not indicate any leakage but that only makes measurements with a few volts available from the battery. We need to know what the leakage is like at operating voltages ie 240v ac. Firstly I lifted the motor onto a pad of dry cardboard as an insulator and connected mains neutral to the motor casing. With one end of my light bulb connected to the live, the other wire was touched on the case, to prove the lamp lit, which it did. Then I probed all the other terminals showing that it did not light indicating no severe leakages. Next I connected an AC ammeter in series with the lamp and repeated testing of all the windings and measured no more that a few hundred micro amps at the worst point. Now this is by no means perfect but given the age of the motor, I felt is was safe enough to proceed with further testing.

Figure G6 Worst-case leakage current observed

From now on I have the motor with a separate earth lead permanently connected during all testing. This means that the effect of minor leaks will be conducted to earth, and in the event of anything more serious, a fuse will blow.

So finally a full test of the motor wired directly to the controller and I'm pleased to say that all went well, and the motor started first time and ran quietly.
Even with the obvious current reduction offered by series parallel starting, the peak starting current was 34 amps!

Figure G7 Peak Starting current

So although the off load running current was 10 amps and the rated full load current just over 13 amps I would recommend that this motor be run from a dedicated circuit on correctly sized cables protected by a type C 20 or 32 amp MCB.

On the following pages are the instructions printed on the inside of the Stayrite controller and the related wiring diagrams.

AEI - STAYRITE SINGLE PHASE POWER DRIVES STARTING UNITS TYPE CSU

Examine the equipment, and if found to be damaged, advise carrier and supplier. Please retain equipment in your possession and await instructions.

GENERAL

These starting units have been specially designed for use with AEI STAYRITE single-phase capacitor start, induction run motors. Before installing a unit, verify that horsepower and frequency, given on the starter nameplate, agree with those on the motor, also that your supply voltage is within range of voltages stamped on the motor and starter. Remove interior packing carefully, see that moving parts are free and that no part is damaged or displaced.

Mount the starter rigidly on a vertical surface which is free from vibration, and connect the starter case to EARTH. When closing the cover do not overtighten the fixing screw.

N.B. It is advisable to make the connections to the supply through a suitable switch-fuse to provide isolation and short circuit protection.

The starters are of the pushbutton contactor type with inherent undervoltage protection and controlled by integral START/STOP buttons. Should it be required to add remote START and/or STOP buttons, this may be done provided the remote START button is of the self resetting type. The starters are fitted with' a manual reset-overload device. If the device trips, it may be reset after a sufficient cooling period by depressing the RESET button. The motor may then be re-started.

The overload protector is fitted with heaters to suit the full load conditions of the motor with which the starter is supplied.

OVERLOAD CALIBRATION

The correct heater and setting, is given in the table below:-

Motor Full Load Current (amps)	6.0	6.5	8.0	8.3	12.0	13.0	16.0	16.5	26.0	34.0	36.0	38.0
HeaterCode andNumber	P/5.9	P/5.9	Q/7.9	Q/7.9	T11.6	T11.6	U/13.2	U/13.2	V/17.5	U13.2	V17.5	V/17.5
Calibration Lever Setting Number	100	110	11	105	105	110	120	125	150	130	105	110

For full load currents not listed set the calibration lever to the value corresponding to:-

Under 26 amps FLC $\frac{\text{Motor Full Load Current}}{\text{Number on Heater}} \times 100$ Over 26 amps FLC $\frac{\text{Motor Full Load Current}}{2 \times \text{Number on Heater}} \times 100$

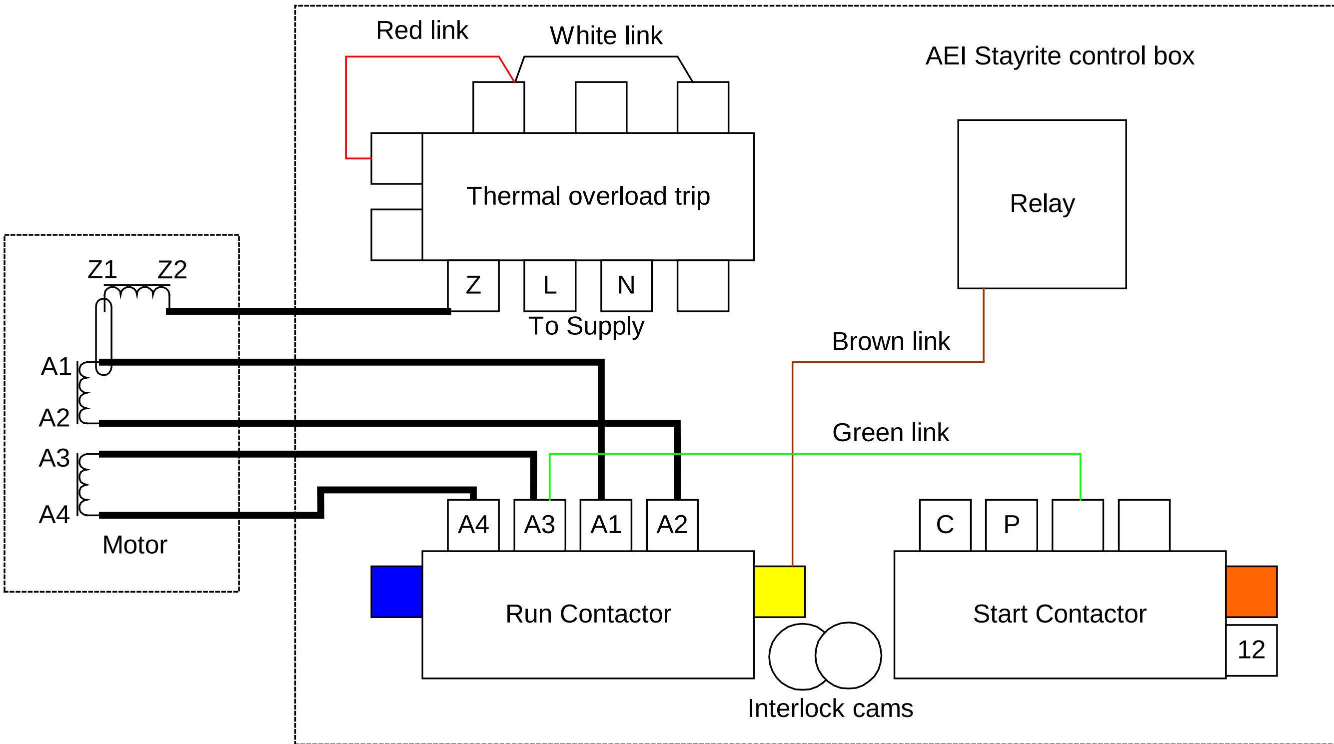
Setting the lever higher than the value given is liable to result in damage to the motor.

SEMI AUTOMATIC STARTER TYPE CSU

The motor is started by depressing and holding the Start button until the motor runs up to speed. The period during which the Start button is depressed must not exceed 10 seconds or damage to the motor and capacitor may result. On releasing the Start button, the change from start to run will be automatic.

TYPES CSU & CCU SERIES/PARALLEL STARTING

200/250 volt, 50/60 cycle supplies
Connections between 'motor and starting unit must be made in accordance with the diagram in which, the required connecting leads are indicated by heavy black lines

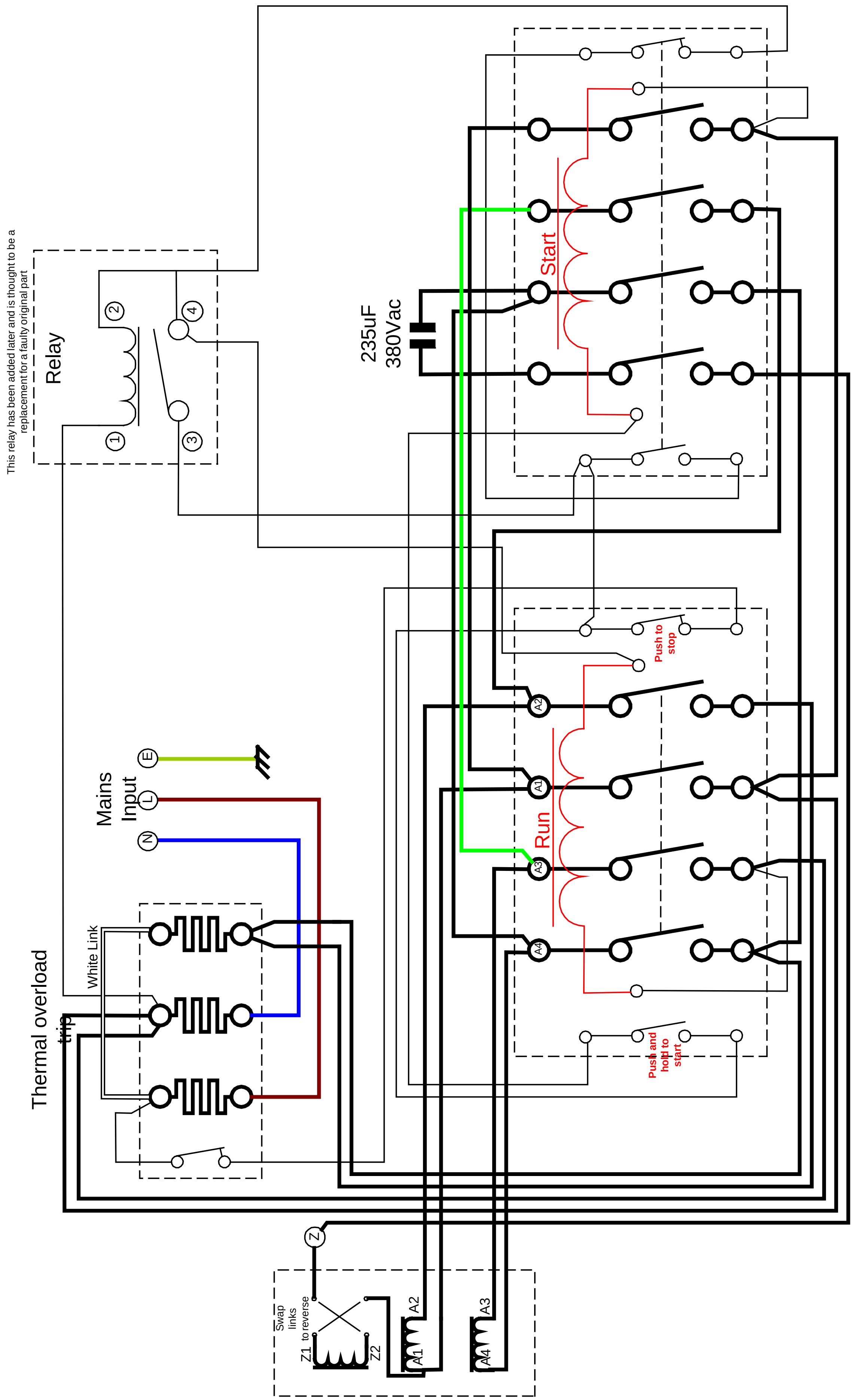


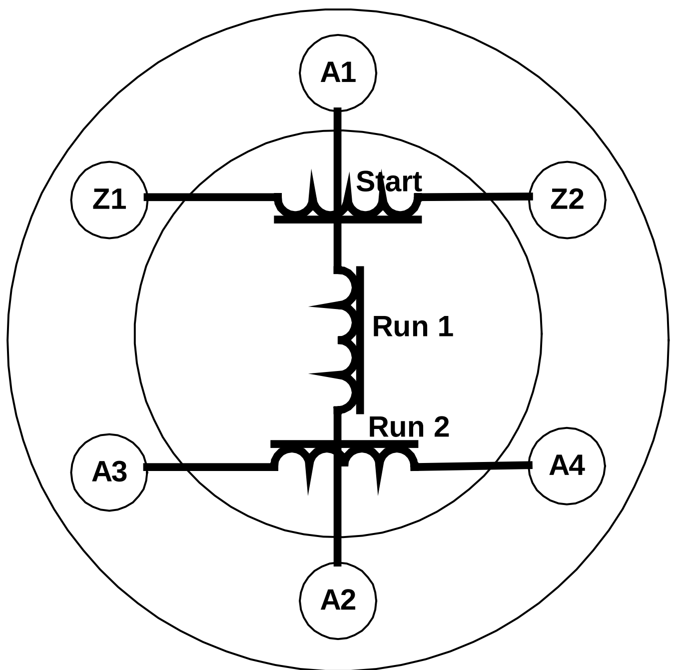
To install an ammeter, remove “White” link and replace with the ammeter.
To install a remote “STOP” button remove the “RED” link and replace with a stop button
To install a remote “START” button connect across “YELLOW” terminal and “BLUE” terminal.
To install auto control (CCU only) connect float switch etc across “YELLOW” terminal and “BLUE” terminal and remove “BROWN” link
To reverse motor, change link in motor terminal box from A1-Z1 to A1-Z2 and connect motor terminal Z1 to starter terminal Z.

IMPORTANT

HIGH TORQUE: - Where a starting current of 5 times full load is permissible, a starting torque of 150 – 200% full load torque may be obtained by removing the “GREEN” link and making a connection between the “ORANGE” terminal and terminal “12”. REMOVE THE INTERLOCK CAMS.

AEI "Stayrite" motor control box



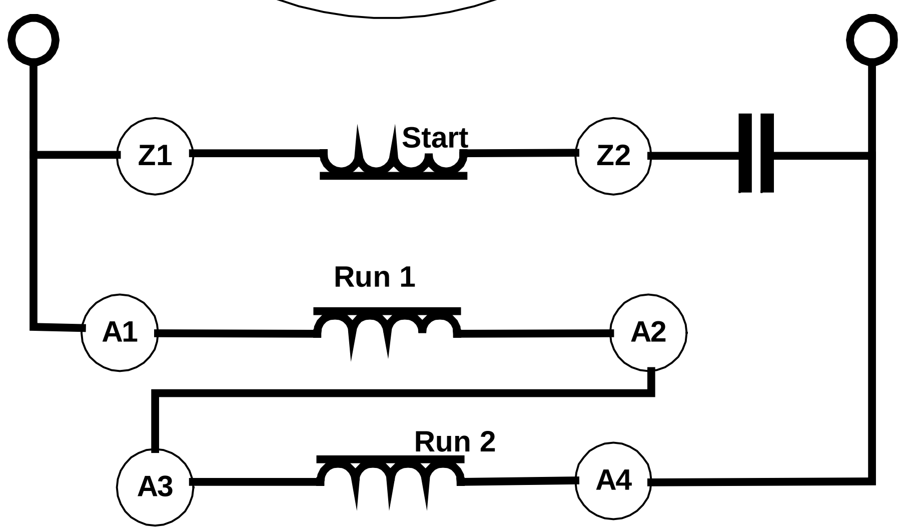


English Electric single phase, 3 winding, motor connections

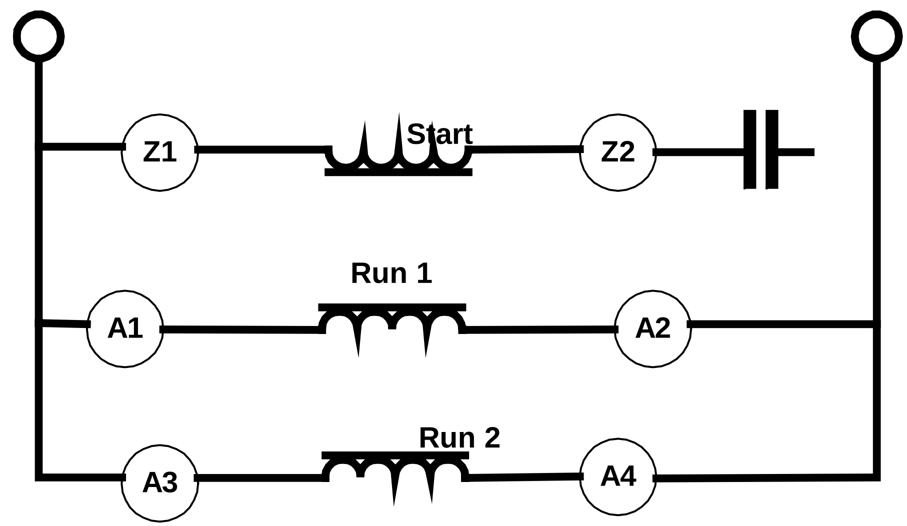
Run windings are connected in series for starting and switched over to parallel for running.

A purposed designed control box is needed for this type of motor and must not use a standard DOL motor starter

The motor can be reversed by swapping Z1 and Z2 connections during starting.



Starting connection



Running connection