Use an SCR or Triac in this

Speed Control for Electric Drills

This simple SCR circuit allows "universal" or AC / DC brush-type motors to be used over a wide range of speeds while still maintaining good torque. While primarily intended for electric drills, it may also be used to control the speed of electric saws, food mixers and movie projectors.

by LEO SIMPSON

An eletric hand drill is nowadays regarded as essential in any home handyman's tool kit, and with most handymen the drill is called upon to perform a multiplicity of jobs. Apart from the mundane jobs of drilling holes and powering various attachments such as circular saws and orbital sanders, it may also be called upon to stir paint and polish the family car. As versatile as the modern drill is, however, the chuck speed is often not low enough, even on the two speed models. This is a problem when larger drills and bits are used, particularly in the case of masonry drills.

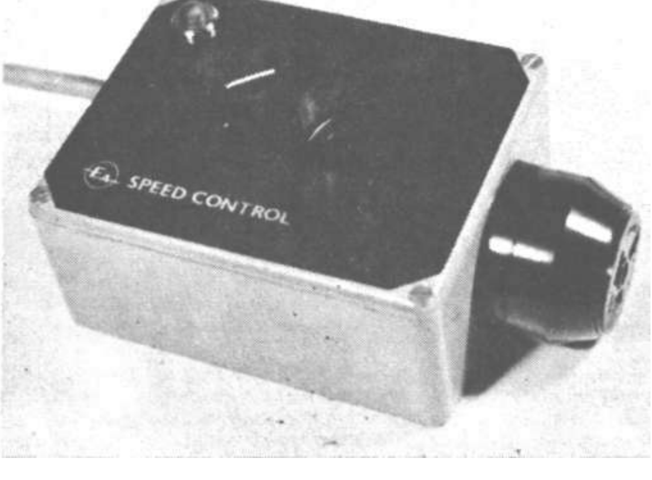
Since the power source is the AC mains supply, the only convenient method of regulating the power fed to the drill motor is to use a thyristor device, either a silicon controlled rectifier (SCR) or a Triac.

The SCR device conducts in one direction only and thus feeds half-wave rectified AC to the motor. It operates in the following way. Basically an SCR behaves like a special sort of rectifier diode which only conducts in the forward direction if it is triggered into so doing by a small positive voltage applied between gate and cathode. When the anode to cathode current drops to zero or the anode-cathode voltage reverses, the device turns off, whereupon it must be triggered into conduction again when required by a further application of voltage between gate and cathode.

An SCR is used to control the AC power fed to the load by varying the instant during each positive half-cycle (ie, when the anode-cathode voltage is positive) at which it is triggered into conduction. If the SCR is triggered early in each positive half-cycle, considerable power will be delivered to the load. On the other hand, if it is triggered late in each positive half-cycle, very little power is delivered to the load. This method of control is referred to as "phase control" since the phase of the SCR trigger point is varied with respect to the phase of the AC supply voltage.

The same method of control can be used with Triacs, except that Triacs conduct in both directions and can be triggered by positive or negative voltages applied between gate and terminal-1, the latter being the Triac equivalent of the SCR cathode.

The most economical circuit for motor speed control is very similar to that for a light dimmer using a Triac and diac. Such a circuit was published in the December 1969 issue of "Electronics Australia". This type of circuit will allow motor operation over a wide range of speeds but is really only suitable for motors that run at a constant load such as fans on furnaces and air-conditioners. If the load on the motor varies, as is the case with electric drills and similar appliances, some means of sensing the speed is necessary so that the circuit can adjust to a changing load condition.



The Speed Control was housed in a compact diecast aluminium box which is suitably robust.

Unless a separate tachometer is used to measure the actual speed of the motor shaft, the only convenient way of monitoring the motor speed is to measure the back-EMF of the motor. (Back EMF is defined as a voltage developed by a motor which opposes the supply voltage.) The back EMF of any motor is basically a function of the speed but there is a problem with the motors used in hand drills and food mixers.

These are so-called universal motors — AC / DC series motors with commutators. The instant during each half cycle at which the SCR is triggered should be controlled by the back-EMF, but at the time the back-EMF is monitored, the SCR is not conducting and thus the field of a series motor is not excited. This means that with this type of motor, the actual back EMF monitored by the circuit will depend on the remanent magnetism of the motor and this will be a function of the current drawn in preceding half cycles.

In this respect, series AC / DC motors are not as convenient as shunt wound or permanent magnet motors which have an essentially constant field strength and hence a back EMF which is related to speed.

In the circuit, the motor is supplied with half-wave rectified AC via an SCR. As we shall see, this allows the motor back-EMF to be easily monitored and a wide range of operating speed to be achieved — wider in fact, than if full wave control was used.

The SCR used in the circuit can be one of three types that are readily available through parts suppliers : the C122D made by General Electric, the BT101 / 500R made by Philips and the 2SF28 made by ITT. These SCRs have a current rating of around 6 amps rms and a breakover voltage of 400V or more. For triggering, they require a positive voltage between gate and cathode of approximately 1 volt. Other SCRs with similar ratings may also be used.

As can be seen from the circuit, the SCR is connected in series with the output socket so that when the SCR is non-conducting, no power is supplied to the motor. A resistor chain consisting of a 10K and 1.8K resistor and a 2K potentiometer provide a positive-going reference voltage for the SCR gate, via diode D2. Diode D1 reduces the power dissipation in the resistor chain by half and protects the SCR gate when the supply voltage reverses and the load is open-circuit, as, for example, when the motor is switched off. Diode D2 isolates the trigger circuit when the SCR is in the conducting state.

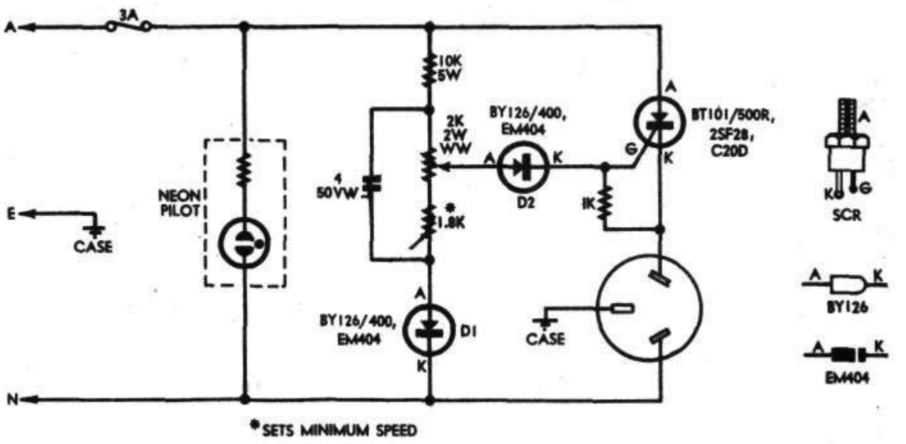
The triggering voltage for the SCR is controlled by the setting of the 2K potentiometer. During each positive half-cycle of the AC supply (when D1 conducts) the pot provides a sinusoidal triggering voltage with amplitude variable from 20V to 50V RMS approximately. This is applied to the SCR gate via diode D2. The capacitor connected across the potentiometer should be ignored for the moment.

The voltage supplied from the potentiometer is not the total effective SCR triggering voltage, because the motor is connected in series with the SCR cathode. This means that the SCR cathode is raised

above the zero reference supply line (ie, the mains neutral line) by the motor back-EMF, so that the effective SCR triggering voltage is really the pot voltage minus the motor back-EMF. Thus, we have negative feedback from the motor so that the circuit will tend to maintain a selected motor speed despite load variations.

As the motor gathers speed, the back-EMF will rise in proportion. It should be noted that there are actually TWO different back-EMFs: one present during the negative half-cycles and the early part of the positive half-cycles when the SCR is not conducting, and the other present during the conduction periods of the SCR. It is the former which concerns us and was referred to above; this is the back-EMF which controls the firing point of the SCR.

As the motor back-EMF rises with increasing speed, the effective SCR triggering



SCR DRILL SPEED CONTROL

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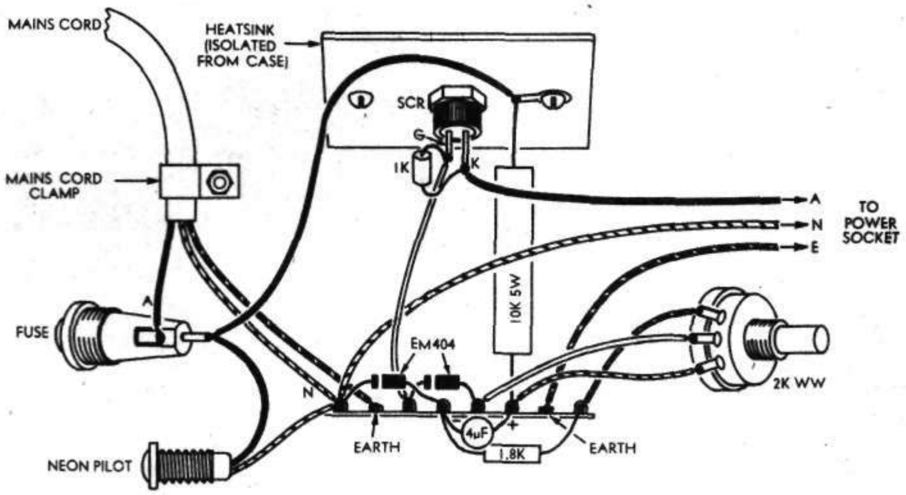

The circuit should be used in conjunction with the wiring diagram to ensure straightforward assembly. The heatsink is isolated from the case by insulating pillars.

PARTS LIST

1 *Diecast box, 120 x 95 x 5mm*
1 BT101/500R, C122D or 2SF28 silicon controlled rectifier
2 EM404, BY126/400 or similar silicon power diodes
1 4uF / 50VW electrolytic capacitor
1 10K / 5 watt resistor
1 1.8K / ½ watt resistor
1 2K wirewound potentiometer
1 IK / ½ watt resistor
1 240V neon pilot light assembly
240V neon pilot light assembly
1 3A fuse and fuseholder
1 3-pin mains socket
2 12mm insulated standoff pillars
1 Control knob
1 8-lug tagstrip
Mains cord, plug, mains cord clamp, rubber grommet, heatsink for SCR, connecting wire, screws, nuts, lockwashers, solder.

voltage is reduced **so** that it is triggered later in each half-cycle and supplies less power to the motor. The motor speed ceases to rise when the SCR triggering voltage is reduced to a level where the SCR is only just supplying sufficient power to the motor to maintain its selected speed.

If the load on the motor increases, it will tend to slow down and the back-EMF will be reduced accordingly. This increases the effective SCR trigger voltage so that it conducts earlier in each positive half-cycle. The motor thus receives more power to maintain its selected speed.

The circuit as described so far is quite satisfactory if the SCR triggering angle is 90 degrees or less. For this range of trigger angle, the feedback mechanism works well, compensating for motor speed changes by delaying or advancing the trigger point of the SCR, as required. However, if lower motor speeds are required, corresponding to an SCR trigger point later in each positive half-cycle than 90 degrees, the above feedback mechanism will not work.

If for example the SCR is already firing at 90 degrees and the motor speed tends to rise, due to a reduction in loading, the gate trigger voltage necessary for the SCR to be triggered will not be available, since at 90 degrees, the gate voltage is at maximum. This means that the SCR will not conduct during the next half-cycle, and it will remain non-conducting until the motor speed drops below the selected speed.

The feedback mechanism will not work for trigger angles greater than 90 degrees with a sinusoidal gate voltage waveform, since the slope of the gate voltage becomes negative after the 90 degree angle. Thus it is not possible to have stable motor operation at very low speeds with the circuit so far described. The motor will tend to "hunt" or "cog" as it attempts to adjust to a stable operating mode.

The remedy for this problem is to connect a suitable capacitor, namely the 4uF component shown, across the potentiometer. This produces a time delay in the pot wiper voltage, so that it continues rising for most of the positive half-cycles and only reaches a peak near the end. The result is reliable triggering over a greater proportion of the half-cycle, and considerably smoother running at very low motor speeds.

The 1.8K resistor in series with the potentiometer sets the. minimum speed of the motor. If the value is too low there will be a "dead spot" at low settings of the potentiometer. If the value is too high, the minimum motor speed will be too high.

We must point out that any speed control circuit such as this cannot possibly be ideally suited to every motor it is likely to be used with. In some cases, its performance will be poor, due perhaps to the motor concerned having very low remanence. Ideally, a circuit such as this should be designed to suit a particular motor, but this is not possible here.

With the SCRs specified, the speed control will be suitable for use with AC / DC motors with nameplate ratings up to 3 amps. This rating ensures that even if the motor is stalled, the resultant "locked rotor" current is not in excess of the ratings on the SCR. A fuse is also included to protect the SCR against more than momentary overloads.

We do not recommend the substitution of higher rated SCRs to enable higher power operation. If a higher power control is required the circuit should be re-designed to suit the different characteristics that can be expected from higher power motors. On no account should a speed control such as this be used with induction motors.

Higher power operation could have been achieved had we elected to use full wave control. This would require a bridge rectifier across the mains to supply the SCR. However, there is the disadvantage that it would not be possible with this simple type of circuit to obtain stable motor operation at SCR trigger angles in excess of 90 degrees. A simple capacitor arrangement cannot be used to delay the trigger point, as in a "half-wave" circuit, so that a more complicated trigger system would have to be used. Also

the circuit would require a diode connected directly across the drill motor field winding, to ensure that the SCR would stop conducting at the end of each half-cycle. We felt that these additional complications were not worth the advantage of slightly higher available power.

Components to suppress radio interference have not been included in the circuit. Although the SCR switches on extremely rapidly, as does a Triac in a light dimmer circuit, the effective power being switched by the SCR is low. This is because the inductance in the motor stops any rapid rise in current, in contrast with what occurs with an incandescent lamp load in a light dimmer. In actual fact, the radio interference generated by an AC / DC brush type motor running from this type of SCR speed control circuit is less than if it is run directly from the mains. There is no reason why RF suppression capacitors should not be included, but for best effect they should be mounted in the motor housing itself.

The construction details of the speed control are quite simple, as may be seen from the photographs. While the approach we have used is not the only one possible, we do recommend that the unit be housed in a sturdy container, preferably a diecast box. The box we used measures 120 x 95 x 55mm and is available from most parts suppliers.

The SCR is mounted on a small heatsink measuring 60 x 40mm, made from 18-gauge aluminium. Since the case of the SCR is at mains potential, the plate must be isolated from the case by two insulating pillars. Take care that the SCR's threaded stud has at least 3mm clearance from the case.

As with many other SCR circuits, a Triac device may be substituted if its ratings are suitable. In fact the thyristor actually pictured in the photograph is a Triac. It has a current rating of 6 amps and is likely to be cheaper than the SCRs specified. In this circuit, a Triac will behave in exactly the same way as an SCR, triggering only on positive half-cycles. It will not give full-wave operation.

Most of the circuitry is mounted on a miniature 8-lug tagstrip, as shown by the wiring diagram. The 10K resistor is wired between a solder lug on the SCR heatsink and one of the tags on the strip. While we have used a 10 watt resistor, a 5 watt unit will be quite adequate. Note that none of the components in the circuit should make any physical contact with the metal case, which is earthed. An exception can be made in the case of the 10K resistor, if this is a ceramic-cased type. Here contact with the case will allow the resistor to run cooler.

The mains input cord should be passed through a grommetted hole in the case and securely anchored with a mains cord clamp. The earth wire is terminated on one of the lugs of the tagstrip which form the tagstrip feet. It is most important that you ensure to make a good earth connection to the case — for safety's sake. The output to the drill is via a standard 3-pin socket.

Note that with some SCRs having very low gate trigger voltages, the 1.8K resistor will be too high, so that the drill will run at a constant high speed, regardless of the setting of the speed control. The 1.8K resistor should be reduced to give a suitable minimum drill speed, with the potentiometer at minimum setting.