APPLICATION NOTE

AN-312

SELECTION OF SCR's FOR SINGLE PHASE DC MOTOR DRIVES

The continuing search for circuit simplicity and low cost in motor speed control has led many designers to SCR controls. Because of their inherent reliability, long life, silent operation, and high efficiency, SCR's are now widely used in motor control circuits.

The circuit in Figure 1 is a full wave bridge feeding the armature of a dc motor through a single controlled rectifier. The speed of the motor is controlled by appropriate firing of the controlled rectifier at various angles with respect to the applied voltage which results in phase control of forward current through the controlled rectifier.

After every half cycle of forward current, the controlled rectifier must recover its forward blocking state. This means that the device must turn off during the time interval between the cessation of forward current and reapplication of forward voltage. A quick analysis of the applied voltage wave shapes would lead one to believe that the time interval between forward current cessation and reapplication of forward voltage is zero. However, in analyzing the circuit, one can see that the time required for the voltage to overcome the threshold voltage of two diodes and the controlled rectifier in series, is the time during which the device can recover to its blocking state. Threshold voltage is that voltage required across the diode or controlled rectifier to cause substantial forward current to flow. Threshold voltage is approximately 0.6 volts.

With an input of 230 volts it would appear that the time interval provided by the threshold voltages should be approximately 23 microseconds, as seen in Figure 2.

Turn-Off Time

Voltages and wave shapes observed in laboratory tests of this circuit, as illustrated in Figure 3, show that in one

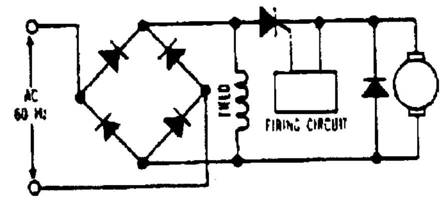

Figure 1 – DC Motor Control

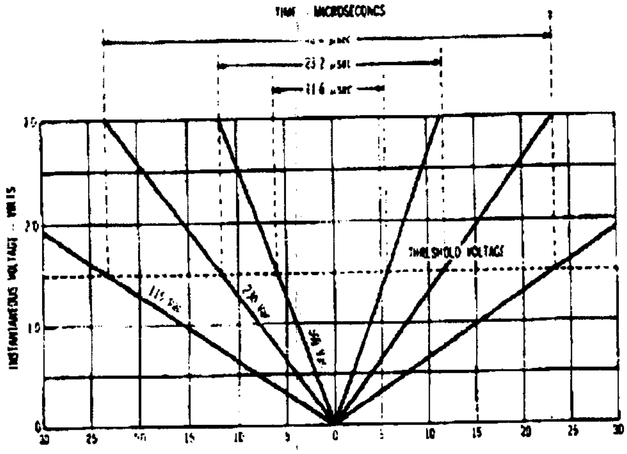

Figure 2 – Interval of Zero Current Flow

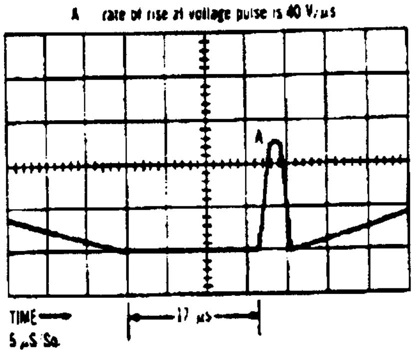

Figure 3(a) – Turn-Off Time

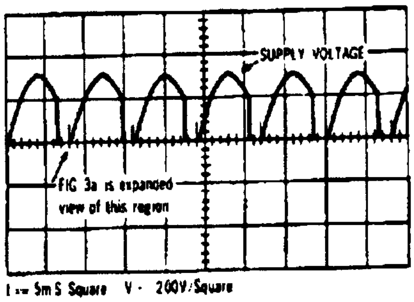

Figure 3(b) – Turn-Off Time

case from the time the forward current dropped to zero (indicated by zero forward voltage drop) to the time of the voltage transient, there is approximately 17 microseconds. This time interval is less than the anticipated 23 microseconds. We can see that with this circuit one critical parameter requiring careful definition is turn-off time. Turn-off time is defined as the time from the end of forward current flow to the reapplication of forward blocking voltage. The industry has standardized on certain test conditions for various size devices. These test conditions are: peak forward current, rate of rise of reverse current, peak reapplied forward blocking voltage, rate of rise of reapplied forward blocking voltage, and junction temperature. An increase in rate of rise of reapplied blocking voltage or reduction in reverse current increases the amount of time required for turn-off.

Getting back to Figure 3, the voltage transient is interesting in that it is 30% of the peak supply voltage, is five microseconds wide, and the rate of rise of the leading edge is 40 volts per microsecond. This particular voltage transient was seen for both resistive and inductive loads.

Thus, we see that instead of 23 microseconds allowed for turn-off, we have only 17, a much more stringent requirement on the controlled rectifier. Also, we can see from Figure 3 that the reverse voltage necessary to help sweep carriers from the forward blocking junction is zero. Therefore, with no reverse voltage to help sweep out carriers, the turn-off time requirements is much more difficult to meet.

We see that in this case the device must recover by itself, i.e., natural recombination of carriers in the junction. Normally, for a controlled rectifier to turn off fast when a diode is connected anti-parallel to it, the turn-off time measured under standard conditions is below 20 microseconds. Experimentally, it has been found that for a device to function in this motor control circuit, the turn-off time requirement will be below 20 microseconds when measured under standard conditions. While it might seem that 20 microseconds far exceeds the 17 we mentioned before, the normal design considerations for the heat sink allow the device to operate below rated junction temperature. This in turn causes the turn-off time of the device to be much shorter than its [illegible]

Test Vs. Circuit Conditions

Shown in Figure 4 is a curve of normalized turn-off time (measured under standard conditions) vs. junction temperature. This curve illustrates that by reducing the junction temperature 25 degrees (from 125 to 100 degrees) the turn-off time will be 80% of what is measured at 125 degrees junction temperature. This means that a device measuring 20 microseconds turn-off at 125°C would measure about 16 microseconds at a 100°C.

As noted before, turn-off time is usually measured throughout the industry under certain conditions. While the observed operating conditions are not standard (for turn-off time measurements) a correlation between circuit commutated turn-off time and circuit commutated turn-off time measured with a diode anti-parallel to the controlled rectifier has been observed.

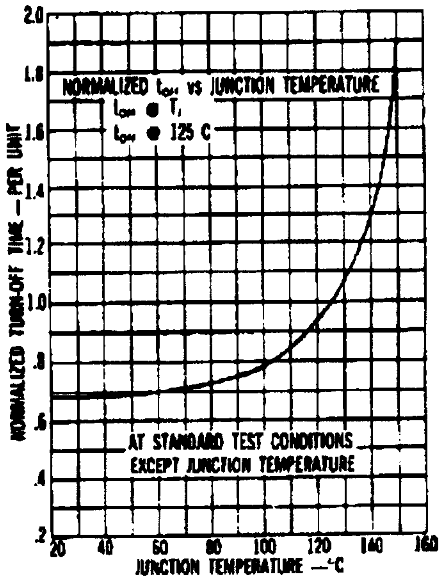

Figure 4 – Normalized Turn-Off Vs. Junction Temperature

Standard turn-off time is known as circuit commutated turn-off time because circuitry causes the reversal of current through the test device which in turn causes the controlled rectifier to turn off.

When a diode is connected in anti-parallel to the controlled rectifier, the reverse voltage (and current) bypasses the controlled rectifier. Turn off time measured under these conditions could be called "starved" circuit commutated turn-off time and more nearly approximated conditions encountered in the circuit under discussion.

During turn-off, the diode in anti-parallel to the controlled rectifier puts a reverse bias of approximately 0.6 volts across the device. The reverse current through the device because of this reverse voltage is negligible and, as expected, the turn-off time measured under these conditions is greater than that measured under standard conditions.

Laboratory tests show that controlled rectifiers measuring less than 20 microseconds turn-off time do not exhibit a large increase (if any) when tested with a diode connected anti-parallel to it. Controlled rectifiers measuring longer than 20 microseconds can double and even triple when tested under these conditions.

Empirically, it has been found that those devices that function properly in 220 V input motor drive circuits, measure less than 20 microseconds circuit commutated turn-off time. However, a turn-off time limit of 22 microseconds under starved circuit commutated test conditions has been shown to give a 99% confidence level of proper circuit operation. This turn-off time is dependent upon the supply voltage as indicated in Figure 2.

Alternative Methods

Fast turn-off devices are not always economical and an alternative is desirable. There are several ways of getting around the turn-off time requirement in this circuit. The obvious solution is to somehow give the device a longer time during which to turn off. One way this can be accomplished is by putting a self-saturating reactance in the ac side of the circuit. This allows more time for the controlled rectifier to turn off by unsaturating at the end of each half cycle, and holding off the appearance of opposite voltage until the reactor saturates again. A method such as this works extremely well and for fractional horsepower dc motors is quite economical.

However, for larger horsepower motors the inductor is quite large, both in inductance required and current capability.

Another method of helping turn-off is to put a capacitor across the load. The capacitor coupled with the distributed inductance of the circuit, will swing the voltage negative at the cessation of forward current and help maintain a counter EMF across the controlled rectifier. This will help sweep out carriers and allow the device to turn off faster. The one drawback to this scheme is that the capacitor during phasing-on periods will draw large amounts of transient current which the controlled rectifier must be able to handle.

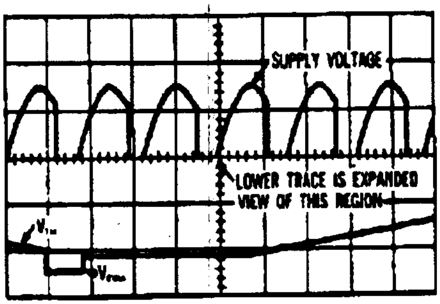

Figure 5 – Voltage Wave Shapes Across the SCR

The voltage wave shapes shown in Figure 5, were taken across the controlled rectifier when a capacitor was connected across the load. We can see that immediately after the forward current conduction the voltage goes negative and helps turn off the device. In addition to this, we see that the transient voltage spike, that is obvious in Figure 3a, has been suppressed. The capacitor across the load does more than just help turn-off by applying a reverse bias; it suppresses the voltage spike which also reduces the severity of the conditions under which the device must turn off.

As a third alternative, the controlled rectifier may be aided in turning off if one or more rectifier diodes are connected in series with it. Doing this will increase the threshold voltage mentioned earlier. In many cases it may be found more economical to do this than to attempt to select extremely fast units, or to use another circuit configuration where turn-off time is not critical. For instance, the turn-off time of the controlled rectifiers in Figure 2 is not critical. However, it is quite possible that it would be more economical to add one or two diodes in series with the controlled rectifier in the circuit of Figure 1 than to use a completely different circuit.

A physical arrangement illustrating how two diodes may be connected in series with the controlled rectifier, at the same time mounting all the rectifying devices on three heat exchangers, is shown in Figure 6.

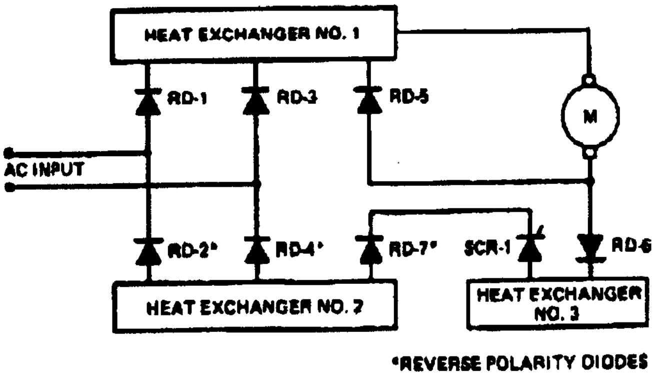

Figure 6 – Rectifying Devices, Including Two Additional Rectifier Diodes, Mounted on Three Heat Exchangers

High Power Systems

This drive is generally not used above 3 hp. There are several reasons. One is that most users prefer to connect larger loads to three phase power supplies as it gives better loading on the power system. Also, as the supply voltage increases, the turn off requirement increases and the larger devices required do not have fast turn off. In addition, large motors don't commutate as well on single phase dc as smaller ones do. They also heat up more due to the high ripple current from a single phase rectifier. Both these drawbacks can be overcome by running the motor at partial load, however this increases motor cost. Generally, the economics of larger motors requires three phase systems.

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