SCR-PUT Model Train Control with "Simulated Inertia"

All the advantages of the SCR-PUT train controller described last month are retained in this new unit, which also includes circuitry to make the model behave just like a full-sized train. It is still very easy to build, and delightfully simple to operate.

by LEO SIMPSON

No matter how good a basic train speed controller is, it cannot achieve truly realistic operation with "direct" control of a low inertia model. Whereas "full throttle" on an actual locomotive simply provides maximum "wheel-spinning" acceleration, on a model loco it results in virtual full-speed operation immediately. Similarly, reducing the throttle to zero causes an actual train to coast for several hundred yards, whereas the model brakes to a skidding halt. This can hardly be called realistic, and in practice the modeller has to use very delicate control to obtain realistic starts and stops, if this is his aim.

The new unit we are presenting here contains circuitry which causes the model to operate as if it had the sizable inertia of a real train. Winding the throttle up to maximum causes the model train to move off slowly and accelerate smoothly up to its designated speed. Similarly, winding the throttle back causes the model train to decelerate smoothly to a lower speed, or to a complete stop, depending on the throttle setting.

As with the design presented last month, the train controller presented here has evolved functionally from its predecessors published in March 1967 and February 1968, but the circuit is markedly different. Our own experience with the earlier controllers and feedback from readers suggested that they were often difficult to drive, especially in low speed shunting manoeuvres. In addition, there were, perhaps, too many setting-up adjustments.

With these thoughts in mind, we have kept the number of adjustments on the new design to a minimum. The unit has but a single control knob, which functions both as throttle and brake. In addition, the unit has a switch which enables the inertia facility to be disabled to give "direct" control for low speed shunting operations.

For the benefit of readers who may not have seen last month's article on the subject, let us briefly describe the principles of operation of three types of model train control: the simple resistor control, the conventional transistor control and the SCR-PUT control which forms the basis of the unit presented here.

Figure 1 shows the basic circuits of all three; each may be seen to include a transformer/rectifier section which converts the AC mains to a pulsed DC output of about 12 to 15 volts. The circuits differ only in the control section used to vary the proportion of this pulsed DC output fed to the model train loco.

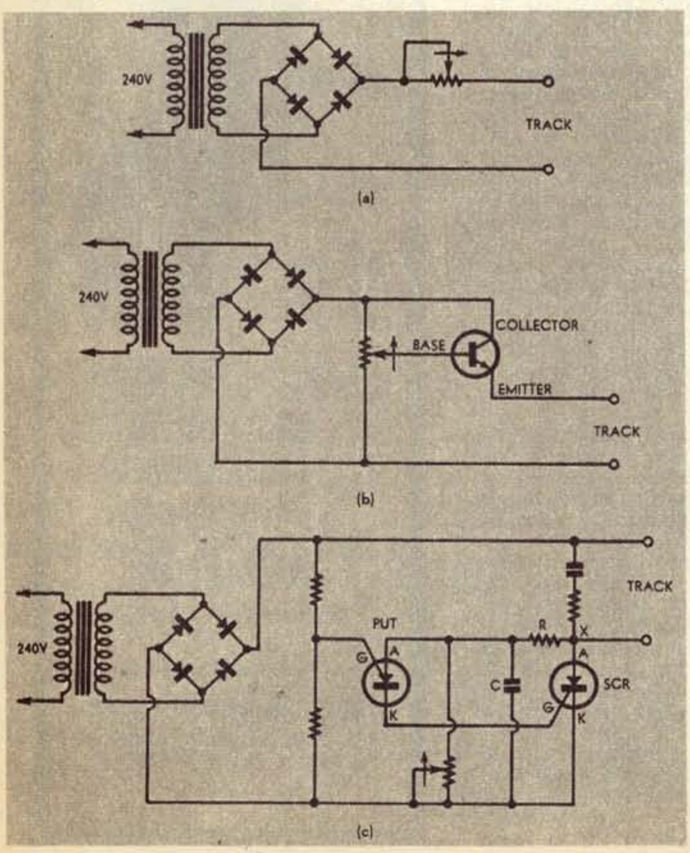
The reason why the output from the rectifier is generally not filtered to give smooth DC is that the "pulsed" DC is more capable of breaking down contact resistances than a smooth DC supply. Contact resistances exist between the loco wheels and the track, between the pickup brushes on the loco wheels and between the motor brushes and its commutator. By more effectively overcoming these contact resistances, the pulsed supply gives improved starting and smoother operation at low speeds.

In the resistor controller of figure 1(a) control is provided by a variable resistor in series with the supply to the track. This controls the current taken by the train directly. As the resistance is decreased, the current increases to make the train run faster. The resistor must be able to pass appreciable currents while dropping a large proportion of the supply voltage. It must therefore be a large and relatively expensive component.

While it has the advantage of simplicity, the resistor has the effect of making the supply voltage to the loco poorly regulated. Whenever additional current is drawn to cope with an increased load, the voltage drop across the resistor increases and the track voltage falls. The load/speed regulation is thus quite poor, particularly at low speeds.

Furthermore, the low speed operation and starting is especially poor because at low throttle settings the voltage applied to the loco is insufficient to reliably overcome the contact resistances.

In the simple transistor controller of figure



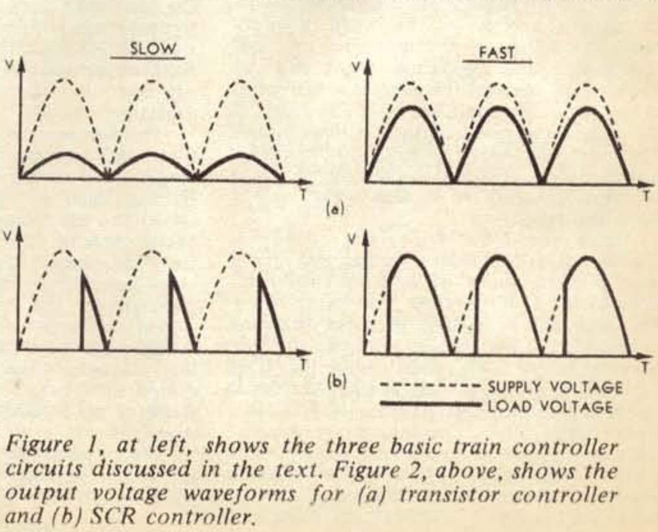


Figure 1, at left, shows the three basic train controller circuits discussed in the text. Figure 2, above, shows the output voltage waveforms for (a) transistor controller and (b) SCR controller.

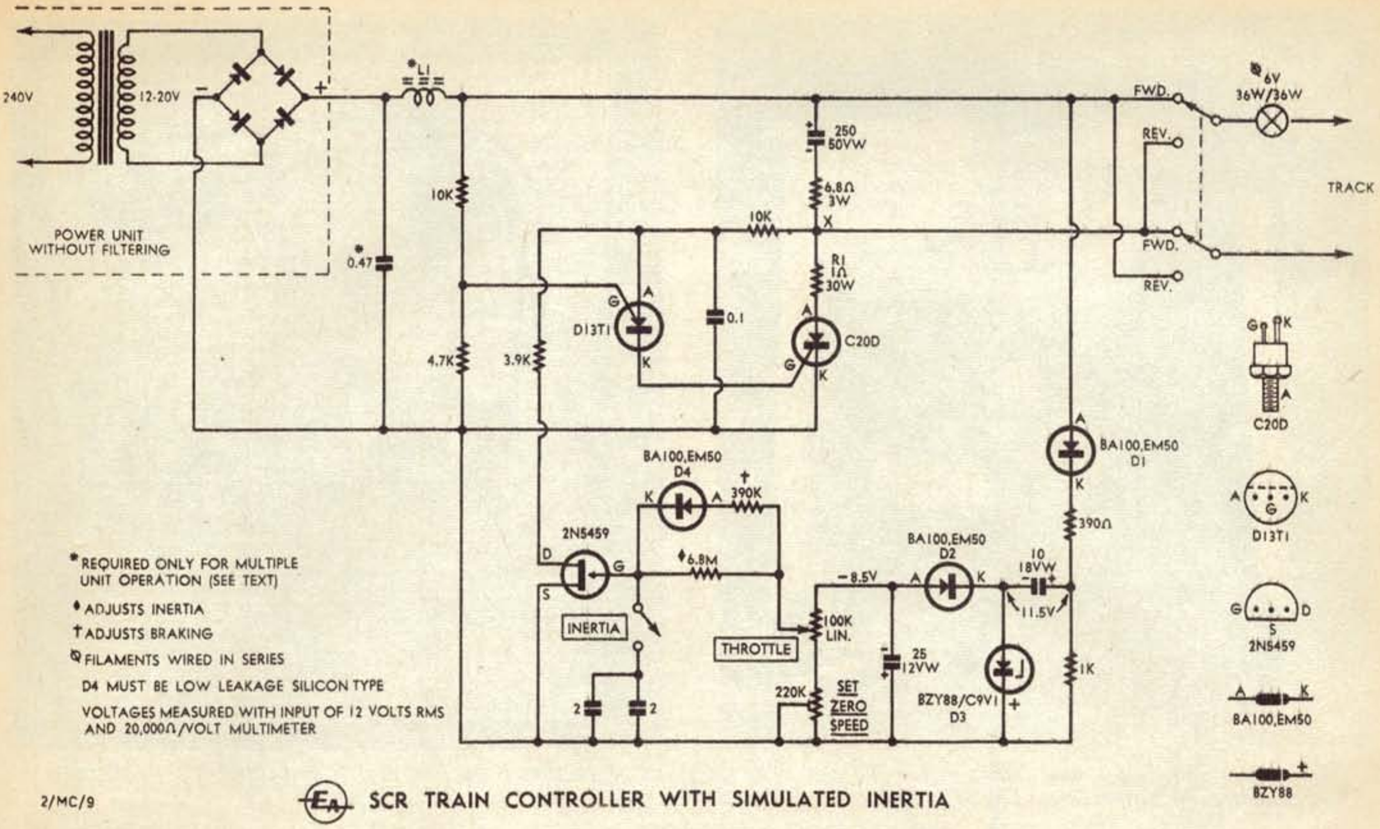


Figure 3. Complete circuit diagram of the new train controller. The lower half of the diagram is the section for simulated inertia. At right is an exterior view of the prototype.

1(b), control is performed by a power transistor in series with the supply to the track. The current through the transistor and the loco is determined by the transistor base voltage, which is varied by a potentiometer.

Like the simple resistive controller, the transistor must be capable of dissipating a considerable amount of power because it drops a substantial proportion of the supply voltage while passing the full load current. The power dissipated in the potentiometer is quite small because the transistor has a considerable current amplification factor.

The current through the transistor and hence through the loco, is dependent on the base current which, in turn, is dependent on the bias voltage applied between base and emitter. Now as the speed of the loco varies, the back EMF (electromotive force, or more simply, voltage) generated by the motor also varies. Because of the circuit configuration, this changes the voltage at the emitter of the transistor, and hence the emitter-base voltage. The result is a negative feedback action: when the loco is moving rapidly and generating a relatively high value of back EMF, less base-emitter voltage is applied to the transistor and accordingly, the latter delivers less current to the track.

Conversely, if the loco slows down, due to increased loading or an upward grade, the back EMF will tend to reduce. This will effectively increase the base-emitter voltage of the transistor and so more current will be delivered. Thus, there is a tendency to maintain the loco speed regardless of changes in loading and gradient; in other words, the circuit gives improved speed regulation compared with the simple resistor controller.

Yet to achieve a really worthwhile improvement in speed regulation over the resistive controller, the transistorised unit needs to be quite complex, as protection circuitry must usually be incorporated. And even with a complex transistor controller the performance is still not as good as with the SCR controller to be described.

Perhaps the main reason why the performance is not up to the standard of our SCR controller is that, like the simple resistive controller, it simply varies the amplitude of the pulsed DC fed to the loco. Thus, at low throttle settings the peak amplitude of the voltage fed to the track is very small and may be inadequate to overcome contact resistances.

Unlike the resistive and transistor controllers, the SCR circuit shown in figure 1(c) does not function by merely varying the amplitude of the pulsed DC. Rather it behaves as a switch, which is rapidly opened and closed to let through varying amounts of power.

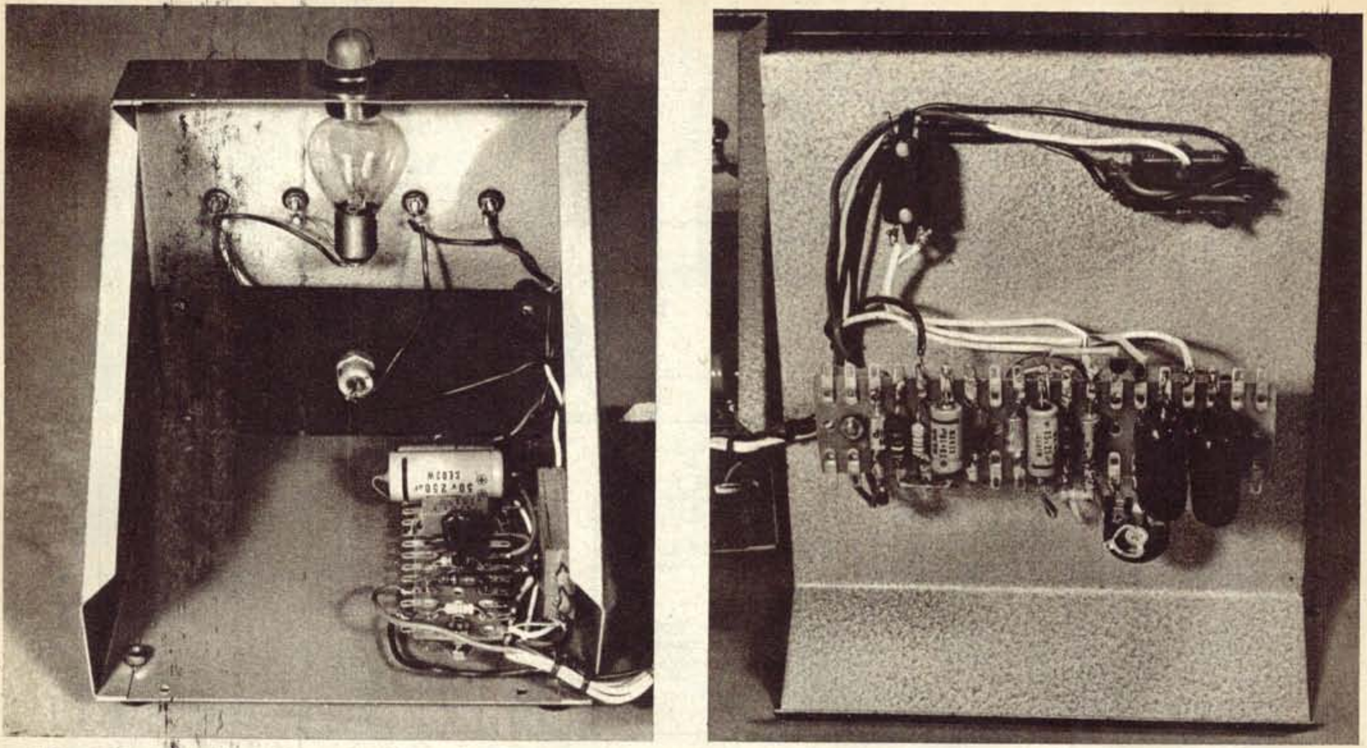
The SCR is a complex thyristor device whose construction and detailed behaviour need not concern us here. Basically, it can be considered to be a special type of rectifier diode which only conducts in the "forward" direction when it is "triggered" into doing so by a small voltage applied between its cathode and a third electrode known as the "gate". Whenever the anode-to-cathode current drops to zero or the anode-cathode voltage is reversed, the device stops conducting, whereupon it must be triggered on again when required.

In the circuit of figure 1(c) the SCR is fed with pulsed DC whose amplitude drops to zero at the end of every half-cycle pulse. The SCR is triggered into conduction during each half-cycle and automatically turns off at the end of each pulse. It is the proportion of each half-cycle pulse during which the SCR conducts, determined by the time at which is is triggered into conduction, which controls the amount of power fed to the loco.

Thus, if the SCR is triggered early in each half-cycle pulse, more power is fed to the loco than if it is triggered late in each half-cycle. This type of control is known as "phase-control" or "pulse-width" control.

Because it is effectively a rapid, low-resistance switch, very little power is dissipated in the SCR. Bulky heatsinks are not required, even for quite high power operation.

The SCR controller has negative feedback from the armature of the train's motor so that, like the transistor controller, its load-speed regulation is good. The main advantage of the SCR controller over the transistor circuit is at slow speeds. Because the output waveform remains relatively high



Two views showing wiring details inside the case. The overload protection lamp is mounted by soldering it to a length of stout tinned copper wire. The SCR heatsink is isolated from the case by four insulating pillars.

in amplitude for all throttle settings, the SCR controller is able to break down contact resistances and give reliable running at much lower speeds than with the transistor controller.

The output voltage waveforms for both the transistor and the SCR controllers are shown in figure 2 for both high and low speeds. The supply voltage from the power unit is shown as a dotted line in each of the diagrams. The output voltage delivered to the track is shown as a solid line. The voltage drop across the transistor or SCR is the difference between the input and output voltage curves.

The difference in the operation of the two controllers can be clearly seen from these diagrams. The transistor controls the amplitude of the output pulses, while the SCR controls the proportion of the input pulses fed to the track.

The transistor controller gives a low amplitude pulse output at low throttle settings which may not always be able to overcome the various contact resistances. The higher amplitude output of the SCR controller, while still having the same "average" value effectively overcomes contact resistances and allows the train to run smoothly at lower speeds. It also helps the train to start more reliably.

The method of negative feedback application in the new SCR controller is unusual and represents a departure in design from that of our previous SCR controllers. These had the drawback that the negative feedback system used effectively applies to the SCR, at the instant of triggering, an instantaneous sample of the motor back EMF. This back EMF will contain a variety of spurious noise signals due to motor commutator hash, wheel sparking, block control switching and so on, which tends to cause erratic and jerky operation, especially at low speeds. The effect is particularly noticeable with the simpler types of loco having motors with a small number of poles and commutator segments; it also tends to be a problem when two locomotives are used in tandem.

To overcome this problem, it is necessary to arrange for the negative feedback mechanism to sample the average value of the motor back EMF rather than the instantaneous value. By averaging the motor back EMF over a short period, we still have the advantage of using negative feedback to improve speed regulation but erratic operation due to spurious noise signals is eliminated.

Referring now to the circuit in figure 1(c), the back EMF from the motor is actually averaged by the same RC circuit which is used to determine the SCR triggering point. In effect, the circuit is arranged so that the motor back EMF is subtracted from the supply voltage fed to the RC network, giving the required negative feedback action.

Actually, the SCR is not triggered directly as in our previous circuits, but is triggered by sharp pulses fed to its gate by a second thyristor device known as a "programmable unijunction transistor", or PUT. The PUT is very similar to a low power SCR but is triggered by a small voltage applied between gate and anode instead of between gate and cathode in the case of an SCR.

The PUT used here is the General Electric D13T1, a low cost type. In the circuit shown, the gate electrode is connected to a reference voltage which is derived from the pulsed DC supply via a voltage divider. When capacitor C charges up via resistor R to raise the voltage at the PUT anode by about 0.6 volts above that of the gate, the PUT conducts and delivers a sharp pulse of current to the gate of the SCR.

LIST OF PARTS

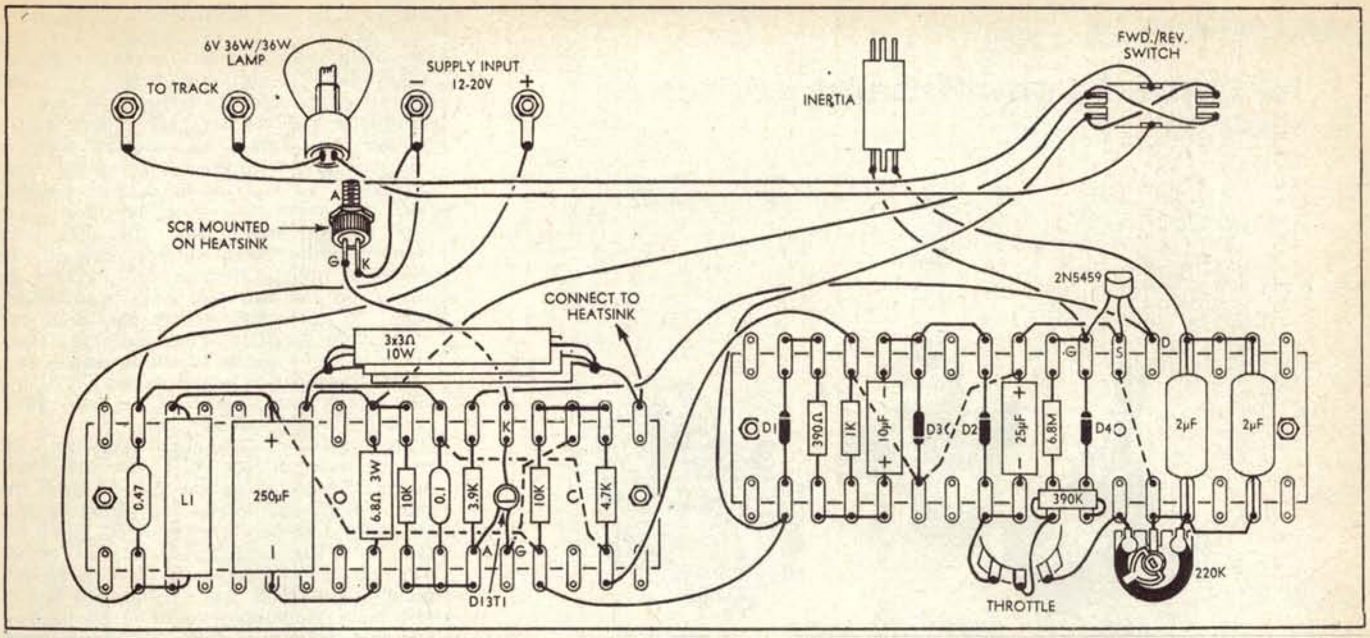
1 Sloping front case, 6 x 6 x 6in
1 Front panel, 6 x 6in
1 Heatsink, 5½ x 2½in x 16 SWG aluminium
1 Large Bezel assembly
1 6 volt 36-36watt twin filament lamp
1 DPDT toggle switch
1 SPST toggle switch
1 Control knob
1 RF choke (see text)
4 Spring-loaded terminals, assorted colours
4 ½in insulated standoff pillars (to mount heatsink)
2 17-lug miniature tagboards

SEMICONDUCTORS
1 C20D silicon controlled rectifier
1 D13T1 programmable unijunction transistor
1 2N5459 N-channel field-effect transistor
3 BA100 silicon diodes
1 BZY88/C9V1 zener diode

CAPACITORS
(higher voltage ratings may be used)
1 250uF/50VW electrolytic
1 25uF/12VW electrolytic
1 10uF/18VW electrolytic
2 2uF/50VW metallised polyester
1 0.47uF/50 polyester
1 0.1uF/50VW polyester

RESISTORS
(¼ or ½ watt unless specified)
1 x 6.8M. 1 x 390K, 2 x 10K, 1 x 4.7K, 1 x 3.9K.
1 x 1K, 1 x 390 ohm, 1 x 6.8 ohm/3 watt, 3 x 3 ohm/10 watt
1 x 100K (lin) potentiometer
1 x 220K preset potentiometer

MISCELLANEOUS
Nuts, screws, washers, solder lugs, rubber feet, hookup wire. cable lacing, solder.



The wiring diagram shows the interconnection of all circuit components and should be used in conjunction with the photographs. The tagboard on the left is the basic control circuit while that on the right is for simulated inertia.

This triggers the SCR which then conducts for the remainder of the half-cycle.

The negative feedback action is as follows. At the start of each half-cycle supply pulse, the SCR is non-conducting, having been turned off at the end of the previous half-cycle. Thus when the voltage at point "X" in the circuit begins to rise, its value will be equal to the rising supply voltage less the back EMF from the motor. If the loco is at speed, the back EMF will be high and the voltage at point "X" will be relatively low. Conversely if the loco is moving slowly, or stopped, the back EMF will be small or zero so that the voltage at point "X" will be almost equal to the incoming supply voltage.

The capacitor C will thus tend to charge slowly or rapidly, depending on the motor back EMF. This will cause the PUT and the SCR to trigger into conduction at a later or earlier instant in each half-cycle pulse, thus varying the power fed to the loco. Hence the circuit tends to exhibit good load-speed regulation. The speed of the loco is varied by the potentiometer connected in parallel across capacitor C so that it varies the proportion of the charging voltage at point "X" fed to the capacitor.

A resistor/capacitor network connected across the track form a hash filter. The resistor value is something of a compromise, as too small a value gives unreliable starting due to excess smoothing of the output waveform, while too large a value tends to give jerky operation at low speeds. The ripple current rating of the capacitor and the peak current rating of the SCR must also be taken into account. We have used a 250uF/50VW electrolytic capacitor and a 6.8 ohm resistor in the final circuit and these appear to be close to optimum.

As described, the circuit in figure 1(c) forms the nucleus of both the Basic Train Controller published last month and the modified version presented here. The only major additions are components to protect the SCR from overload, in both circuits, and in the new design additional circuitry to give simulated inertia.

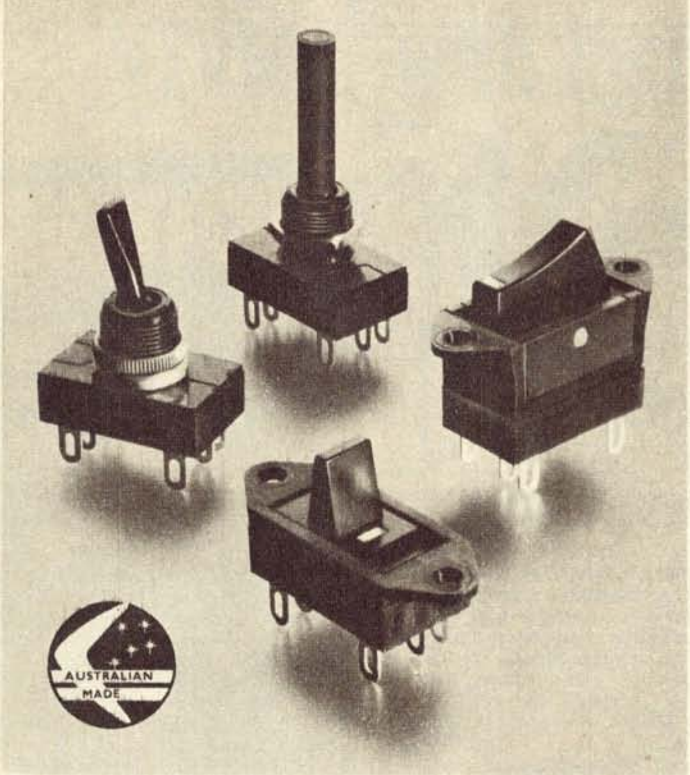
With a conventional train controller, as noted earlier, the only way the operator can simulate the inertia of a full size locomotive is to very gradually wind up the throttle so that the model accelerates smoothly to the desired speed. Similarly, when slowing the loco, he has to gradually wind down the throttle so that the voltage supplied to the loco is very slowly decreased. In most cases, it is just not possible to "finger" the throttle control delicately enough to obtain the desired effect of a real train.

Referring again to figure 1(c), what is required to solve this problem is some sort of electrically controlled resistance element to replace the throttle potentiometer. We could then use slowly varying voltages to control the throttle and so simulate the effect of inertia with models. In fact, this is what we have done. The electrically controlled resistance element we have used is the drain-source resistance of an N-channel field-effect transistor (FET). The FET is controlled by a negative DC voltage applied between gate and source electrodes.

The FET used is a Motorola device, type 2N5459. As with other FETs, it is possible to vary the DC resistance from several hundred ohms to tens of megohms by varying the negative gate-source voltage between limits of, typically, -2 to -8 volts. This means that all that is required to use the FET in our circuit is some means of developing a negative bias voltage, together with suitable RC networks which will allow the gate-source voltage of the FET to be smoothly controlled.

Looking now at the main circuit diagram, readers will notice that it is split into two sections. The upper section is essentially the same as the basic circuit shown in figure 1(c). The lower section is the inertia circuitry.

In the inertia section, diodes D1, D2 and D3 are used to develop a negative DC voltage from the fluctuating positive supply line, as follows. Initially, all capacitors in the inertia circuit are discharged. As the voltage on the positive supply rail begins to rise, D1 conducts and a replica of the pulsed DC voltage waveform appears across the 1K



resistor. The 10uF capacitor charges via D3 to the peak of the DC voltage waveform appearing across this resistor. In the periods when D1 is non-conducting, the 10uF capacitor transfers its charge via the 1K resistor and D2 to the 25uF capacitor. The voltage across the 25uF capacitor tends to become almost equal to that of the 10uF capacitor, but reversed in sign, ie, negative. The 25uF capacitor is thus the reservoir for the negative bias supply. The 390 ohm resistor limits surge current through the diodes at initial switch-on. D1 prevents the charge on the two capacitors from leaking back to the positive supply line and maintaining the SCR in the conducting state. D3 is a zener diode which functions as a conventional diode, as mentioned above, but also limits the voltage across the 25uF capacitor to less than nine volts.

A proportion of the negative voltage is fed to the gate of the FET via the 100K potentiometer and associated resistors. If the gate voltage is small, the drain source resistance will be correspondingly small, so that the 0.1uF capacitor in the PUT circuit will charge relatively slowly. This means that the PUT and SCR will be triggered late in each half-cycle pulse or not at all. Similarly, if the gate voltage is high, the drain-source resistance will be correspondingly high and the 0.1uF capacitor is allowed to charge rapidly so that the PUT and SCR are triggered earlier in each half-cycle.

Thus, it can be seen that the FET is an electrical equivalent to the throttle potentiometer in the basic circuit in figure 1(c). The 3.9K resistor in series with the drain of the FET offers a degree of protection to the FET and also determines the minimum resistance in the circuit.

The 100K potentiometer controlling the FET bias becomes the throttle. The 220K preset resistor connected in series with the potentiometer is arranged to set the zero speed of the loco when the throttle is in its minimum setting. It prevents the gate-source voltage from being reduced below a certain value.

The zener diode D3 limits the maximum negative voltage to less than nine volts, as mentioned above. This is just slightly more than the maximum "pinch-off" voltage of the 2N5459, and so ensures a progressive action in the throttle. The use of the zener also reduces the need to adjust the zero speed setting when the supply voltage is changed.

The voltage readings on the circuit diagram were taken with a rectified AC input of 12 volts RMS and a 20,000 ohms/volt meter. If the AC input is increased, the voltage across the 10uF capacitor will increase accordingly, but that across the 25uF capacitor is held constant by the zener diode. The voltage readings are unaffected by the throttle settings.

Inertia is arranged by switching 4uF of capacitance between gate and source of the FET. When the throttle potentiometer is advanced to a high setting, the capacitor must charge up via the 6.8M resistor and thus the FET bias rises very gradually. The train accelerates accordingly. The amount of inertia on acceleration is most easily controlled by the size of the 6.8M resistor. If a higher degree of inertia is desired then this resistor should be increased and vice versa.

If the throttle was reduced to zero after the loco had reached its full speed, the loco would take a very long time to decelerate to a full stop. Thus, we need extra components to increase the degree of braking when the throttle setting is reduced. This is accomplished by the diode D4 and its series resistor of 380K, which provide a shorter time-constant discharge path. The braking can be increased by decreasing the series resistor and vice versa.

The ability to switch the inertia capacitor in and out of circuit adds to the flexibility of the unit. When the capacitors are switched out of circuit, the unit can be used as a "direct" controller without inertia, in much the same way as the basic train controller published last month. This makes low speed shunting manoeuvres much easier than if the inertia facility was in circuit permanently.

The only features of the circuit diagram remaining to be discussed are the inductor L1 and its associated capacitor, and the components for overload protection of the SCR.

If more than one of these controllers are to be connected to a common transformer/rectifier unit, the inductor L1 and the 0.47uF capacitor should be included. They form a filter which prevents mutual interaction between controllers due to false triggering from switching transients.

Protection against overload is provided by the resistor R1 and the lamp. If a short circuit is applied to the track, R1 limits the surge current to a value which is considerably less than the surge capacity of the SCR specified. The lamp then warms up and limits the steady state short-circuit current to less than five amps, which is again less than the continuous rating of the SCR.

For simplicity, no fuse has been fitted. As far as the SCR is concerned a fuse would offer no extra protection, since the steady current is limited to five amps. However, some constructors may wish to fit a fuse to the power supply circuit so that the transformer and rectifiers are protected against accidental short circuits when making connections to the controller.

The controller may be used with rectified AC inputs of up to 20 volts RMS, which maximum figure should be adequate for all likely situations. With most locos the input voltage should not be any more than 15 volts, otherwise the scale speed becomes excessive and completely unrealistic. As far as the circuit is concerned, the limit is mainly set by the voltage ratings of the PUT. Also, with high input voltages, the throttle tends to become very critical in operation – small movements of the control tending to produce large changes in speed.

A further and perhaps more important consideration is that the input voltage should be limited so that the form factor of the output current waveform does not become excessive at low throttle settings. If an excessive input voltage is used, the form factor (ie, the ratio of RMS value to average value) will be very high and the amount of heat dissipated in the loco motor will be high, at low throttle settings, for the amount of torque being produced. With the maximum of 20 volts we have specified, heat dissipation at low or high throttle settings has not been found to be a problem with the wide variety of locos we have tested with this controller. (See footnote at the end of this article.)

As with the basic controller published last month, one of the advantages of the design is that it may be constructed for high or low power operation with only minor circuit changes. The main circuit diagram shows the components for high power operation, ie, the unit may be used at output currents of up to five amps. By substitution of a lower power SCR, a different overload lamp and a higher value overload resistor R1, a lower power unit may be produced.

For a lower power unit an SCR such as the General Electric C106Y1 or Mullard BT100A could be used, giving a two amp capability. For these devices, the overload limiting resistor should be increased to 3 ohms at a power rating of 10 watts. The overload lamp should be changed to a 12 volt/18 or 21 watt type. An automobile trafficator lamp would be very suitable.

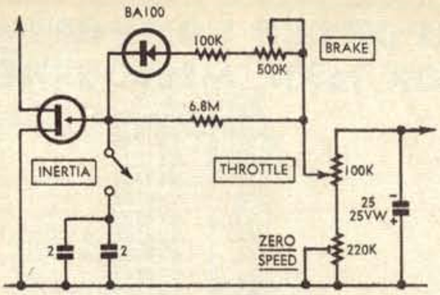


Figure 4: This modification to the FET circuit can be used to provide separate throttle and brake controls.

It is worth noting that a Triac device may be substituted for the SCR if a suitable type is on hand. Economy Triacs such as the SC141D or AC06DR are suitable for direct substitution in the circuit as published. The overload components need not be altered since both Triacs have a current rating of 6 amps.

The main point to be considered when deciding if a particular SCR or Triac is suitable for the unit is that it should have blocking voltage ratings of 30 volts or more. When connecting a Triac to function as an SCR, T2 becomes the "anode" and T1 becomes the "cathode". Thus, if an AC06DR is used as an SCR, the case becomes the anode, the small terminal is the gate and the large terminal becomes the cathode.

Diodes D1 and D2 can be virtually any general purpose type, either germanium or silicon, provided they have a PIV rating of around 25 volts or more. However D4 must be a low leakage silicon type such as the BA100 specified.

The 4uF inertia capacitor in the prototype consisted of two 2uF/100VW metallised polyester capacitors in parallel. If size is not a problem, standard polyester or paper capacitors may be substituted. However if old paper capacitors are used, their insulation resistance should be checked – it should be of the order of 100 megohms or more, for satisfactory operation. Electrolytics, whether aluminium or tantalum types, are not suitable in this application.

The prototype controller was housed in a 6 x 6 x 6in sloping front case. On the front panel are mounted the throttle control, the forward/reverse switch and the inertia disabling switch. At the top of the case is a large bezel which is used for the overload indicator lamp. At the rear of the case are two pairs of spring-loaded terminals, for supply input and track output repectively. All of the inertia circuitry is mounted on a tagboard on the front panel, while the major part of the remaining circuitry is mounted on a tagboard on the floor of the case.

Layout is not critical but good wiring practice should be followed. Most enthusiasts will have their own ideas about the final unit and may wish to house the power supply in the same case. Alternatively, several controllers could be housed in a large console for extensive layouts. Constructors who are

not used to assembling electronic equipment should follow the wiring diagram closely.

The SCR is mounted on a heatsink made of 16-gauge aluminium sheet measuring 5½ x 2½in. This is mounted on four insulating pillars on the rear of the case, so that it is electrically isolated. The heatsink is large enough to allow the controller to be operated at full power into a short circuit, if necessary, without damage to the SCR. It is shown blackened in the photograph but this is not necessary. For low power controllers using the BT100A or C106Y1 no heatsink is required and the SCR may be soldered directly into circuit.

Two 17-lug miniature tagboards are used to accomodate the minor components. The wiring diagram and photographs show the layout. The overload protection resistor R1 consists of three 3-ohm/10 watt resistors connected in parallel to give a 30 watt dissipation rating. The 250uF electrolytic capacitor should have a rating of 50 volts to ensure that it has sufficient ripple current rating. Do not mount the electrolytic capacitor close to the overload protection resistor otherwise it may be damaged due to the heat from the resistor.

The filter inductor L1 is not critical and is wound as follows: Start by winding a layer or two of thin insulation tape on a 1in length of ¼in diameter ferrite rod. If a full length ferrite rod has been purchased, it may be cut to length by filing a nick around the circumference and snapping it as if it was of glass. Close wind 50 or 60 turns of 24 or 26SWG enamelled wire of the insulation tape. Then wind insulation tape tightly around the rod in a couple of layers and the inductor is finished.

The supply input and track output leads are terminated to the spring loaded terminals at the rear of the case. These should be suitably colour-coded and labelled to avoid confusion and the possibility of incorrect connections. We suggest red and black for the positive and negative supply inputs and a different colour for the track terminals.

The overload protection lamp is wired directly into circuit using 16SWG tinned copper wire to support the lamp from one of the track output terminals. The lamp is a 6V car headlamp with the filaments wired in series. It is mounted directly underneath the oversize bezel at the top of the case.

The leads running to the front panel should be bound into a neat cable as shown in the photographs. This makes for neatness and helps prevent damage to the leads due to accidental clamping when the front panel is secured. Make sure that the leads have a free length of about 10 inches before lacing to ensure that the front panel may be swung away for servicing without straining any connections.

The only adjustment to be made when the unit is first connected to the power supply is the correct setting of the Zero Speed potentiometer. This is done by placing the loco on the track and switching the inertia facility out of circuit; then wind the throttle control fully anti-clockwise and adjust the 220K preset potentiometer until the loco neither moves not emits a buzzing noise. This is all there is to it.

Readers who have constructed last month's version and wish to incorporate the inertia circuitry may do so without alteration to the existing circuitry, in spite of the fact that the PUT circuitry in this month's version is slightly modified. The preset potentiometer in last month's version may be simply left in circuit, being adjusted so that the wiper is set to the negative end of the element.

Those readers who built the original SCR control units with simulated inertia as published in March 1967 and February 1968 may update their controllers using this month's circuit. This may be done while still retaining the separate throttle and brake controls. Figure 4 shows the necessary minor modifications to the main circuit diagram. The 100K resistor in series with the 500K potentiometer determines the minimum braking distance.

FOOTNOTE: Some model train enthusiasts decry the use of "pulse power" for model control, as they claim it causes undue heating of the loco motors. This is true only to the extent that for a given torque output, the heat dissipated in the motor will undoubtedly be higher for rectified AC input than for smooth DC. The reason for this is that the torque output is a function of the average value of the current, while the heat produced is a function of the RMS value. For a rectified sine wave, the ratio of the RMS current to the average current (ie, the form factor) is 1.11. With a phase-controlled SCR controller the form factor is higher, especially at low throttle settings.

This means that for a given throttle setting, the heat produced in the loco motor does tend to be higher for an SCR controller than for a resistor or transistor controller using unfiltered DC input. In practice, however, we have not found the heat produced to be any more noticeable than with transistor controllers, and certainly not excessive. Indeed, with the improved low speed running and starting provided by the SCR controller, the small extra heat produced is a small price to pay. ■