Turnout Motors from Servos

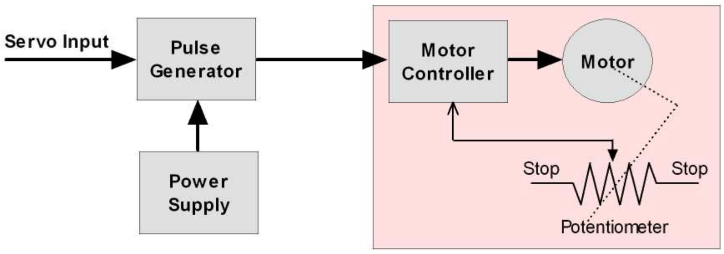
An article by Jim Lomison in the January, 2011 issue of Model Railroader[1] describing the use of motors from servomechanisms to drive turnout points sparked an interest, principally as a means of lowering the cost of turnout motors. The article also raised some points of controversy: The propriety of using servo motors as stall motors, the efficiency of the power supply and the lack of some specific details in the mechanical construction.

Reviewing the ideas presented in Mr. Lomison's article, this document describes and illustrates some alternative methods and attempts to illuminate some of the issues regarding the original article.

A. A Simple Overview of Model Servos

A model servo system is used to position an element in the model to a specific location, for example the rudder on a model airplane The positioning driver provides rotary motion that is usually transferred to linear motion through a wheel or rectangular actuator arm (called a 'horn' in model servo lingo), connected to the motor shaft.

The simplified servo system looks something like this.



Motors used in servos are usually coupled to the output shaft through a gear train. The gears provide higher torque and a lower rotational speed (than that of the motor) to the output of the servo.

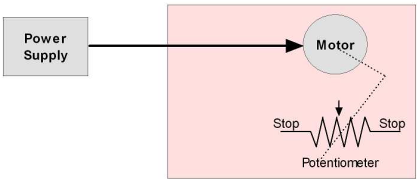
The servo input often comes from a hand held controller, such as that used to control the flight of a model airplane or the motion of a robot. This input causes the pulse generator to output a series of pulses of various widths to the servo (the area in pink). The motor controller interprets the pulses and directs the motor to move to a specific position. The motor's gear train is connected mechanically to the shaft of a potentiometer whose resistance changes as a function of its position. This resistance is transformed into a voltage that is fed back to the motor controller, telling the controller where the motor shaft is, in angular degrees. As the input pulse width changes, the motor shaft changes position proportionally. The potentiometer voltage provides *feedback* to the controller, keeping the system locked in step.

In this kind of servo, the potentiometer ('pot') provides an additional function. The shaft of the pot can usually rotate through a maximum of about 160-185 degrees. A tab in the pot limits its shaft rotation at each end. Since the pot shaft is mechanically connected to the motor shaft, usually through gears, the motor shaft cannot move beyond the limits of the pot shaft. When the pot shaft is at either extreme of travel, the motor is said to be in *stall condition* because it cannot move.

<u>Stalling</u>
A motor in stall condition draws several times the current it normally requires to operate if it is not designed to stall. For example, a small servo motor that requires 0.070 amperes to operate may draw between 0.210 and 0.500 amperes in stall condition. This extra current causes the motor to heat and it can heat to such an extent that the windings on the motor armature open, short circuit, burn up, or heat to such an extend that the motor housing – especially a plastic one – begins to melt or even burn.

Some motors are designed in such a way that they stall 'gracefully.' These are specifically called 'stall motors' and, in fact, usually draw less current stalled than in normal operation. However, this kind of motor is seldom, if ever, used in a servo.

B. Notes on the Lomison Mechanism



Mr. Lomison has chosen to disassemble the servo *system* and use just the motor portion. He has discarded the motor controller and the pot feedback, but has retained the motor-potentiometer gear connection. That means the motor will reach stall conditions when the pot is at either end of its travel.

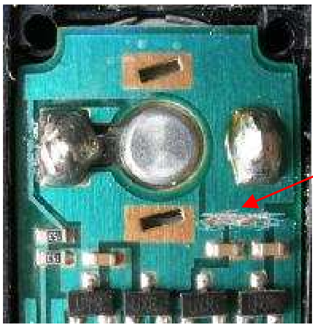
He used the HiTec HS-311 servo motor which has an unusually low stall current and a current that tends to remain constant with small changes in applied voltage. The stall current in my HS-311 motor sample, powered as he suggested, was approximately 80 milliamperes (mA), close to his measurement. The same motor powered at 0.5 volts directly had a stall current of 100 mA and powered at 1.5 volts stalled at 200 mA. The large difference in these numbers is due to the resistance Mr. Lomison adds between the power supply and the motor, which acts to limit the current to the motor, and at the same time, dissipates a large quantity of the power he applies.

The interesting thing is that this motor begins turning at 0.5 volts DC, drawing about 40 mA while running. At this voltage, the speed is close to that of commercial turnout motors and the torque at the output shaft is surprisingly high. This suggests that a low voltage supply of 1.5 volts would be sufficient (60mA running, 200 mA stall). If the motor is prevented from reaching stall conditions while still providing enough holding torque to keep the switch points in place, the power requirement can be greatly reduced.

In his article, the author mounts the principle components of his mechanism directly to the underside of the layout, spotting and securing the motor housing and two lever switches within a rather tight space. If, instead, the components were secured on a separate mounting surface, adjusted for correct operation and then installed to the layout, the installation procedure might be greatly enhanced.

In preparing the servo for his mechanism, the author asks that the circuit card in the HS-311 be removed. In fact, this is not necessary and removes some of the support that holds the motor in alignment with the servo gears. It is necessary, however, to disconnect the motor electrically from the circuit card. This can be done by cutting a trace on the card.

This photo shows the HS-311 servo with the back removed. The motor is on the right side of the housing



The arrow points to the cut in the copper connected to one side of the motor leads.

The three wires that come attached to the servo (black, red and yellow on the left of the photo above) should be unsoldered and removed. Two new wires, one to each contact on the motor are installed.

Here is the completed wiring before the back is replaced. The cut trace is under the yellow wire.

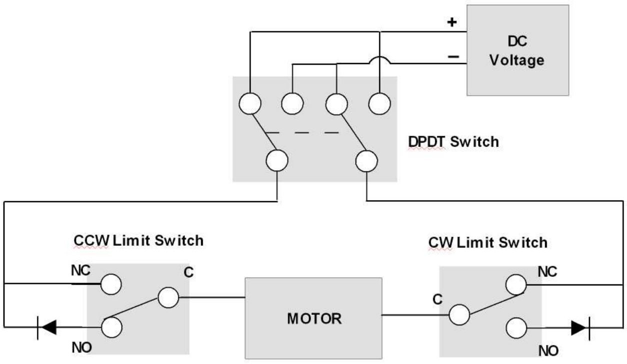
Mr. Lomison does not explain the importance of limit switch positioning nor fully describe the installation of the actuator wire. These topics and a discussion of electrical power will be covered in the modified mechanisms on the following pages.

[1] Lomison, Jim: *Operate turnouts with servo motors*, pps 62-63.

C. Turnout Motor Wiring

The first consideration is an examination of the power consumption of the turnout motor mechanism. Using a stall motor configuration, the Lomison connections require about 1 watt of continuous power for each turnout, most of which is dissipated in the series resistors.

The circuit below consumes about 0.1 watt when the points are in motion and no power when they are locked in position. The motor is kept out of stall condition at all times.



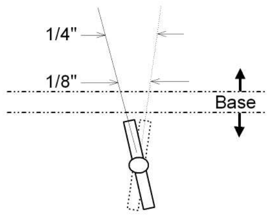
The motor gets its power from the common terminal of the SPDT limit switches. The diodes on the normally-open contacts (NO) prevent a voltage polarity being applied that would move the lever further into a closed position. When the polarity is reversed by the DPDT control switch, the motor begins to move under a voltage reduced by 0.7 volt due to the diode impedance. When the horn clears the lever on the switch, the diode drops out of the circuit and full motor voltage is present.

Since our motors begin moving at 0.5 volt, if we set the motor power supply at 1.5 volts, the diode voltage drop will not interfere with reliable operation. At 1.5 volts we can expect to draw no more than 80 mA and 0.12 watts while the motor is running.

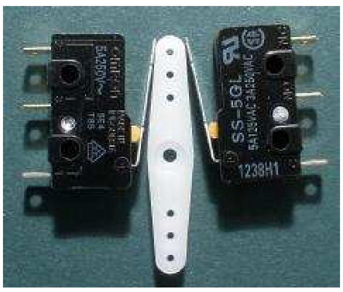
It is apparent that this configuration does not provide contacts for frog power or remote indication of the turnout position. This will be addressed later on.

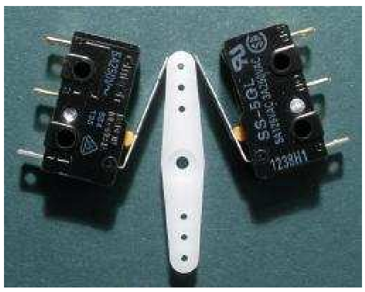
D. Component Positioning and Selection

The second consideration is the arrangement of the motor, horn, limit switches and actuator rod. The relative position of these components is somewhat critical. The turnout points are moved by a wire connected to the horn. The end point of this wire must move only the distance required to move the points, about 1/8" in On30 and HO, half that for HOn30 and N scale.



To assure the no-stall condition, the horn tip must activate a switch at each end of its excursion. The limit switches can be clustered around the horn in a number of ways. For smaller horns, the limit switches can be placed very close. The ends of the limit switch levers can be bent in to restrict horizontal excursion of the horn or the limit switches can be set at an angle for continuous adjustment.





Horns
Horns are usually included with the servo and come in several varieties and sizes in proportion to the servo body. The horn in the photos above is representative of those with the small servos. The tip of smaller horns can be controlled to move close to the requirements of turnout points.

Limit Switches
A small limit switch is the easiest to position. When selecting a limit switch, there are three parameters to consider.

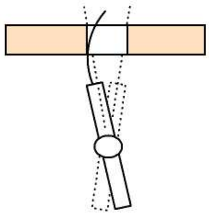
a) Lever type: In this mechanism the actuating force will be applied approximately perpendicular to the lever arm, therefore a straight lever arm is sufficient and better than those with hooks or rollers.

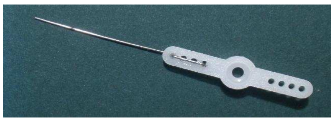
b) Actuating force: Since we want to save most of the torque for the turnout points, the actuating force must be as low as possible. For small switches, this force can range between 1 and 700 ounces! A force of less than 1 oz. is best, therefore the proper switch selection is very important.

c) Size: Large lever switches will be difficult to place around the servo shaft. A number of miniature switches are available that are no longer than half the length of the servo horn. These can be clustered close to the servo shaft and placed to limit the horn movement to less than 0.050".

Servos
The smaller the servo, the less the torque output. Nevertheless, small servos have demonstrated adequate torque to move hinged points up to O scale and non-hinged points from N through On3 and On30 scales. Smaller servos are considerably more economical. The SG-90 is a good choice for making a turnout motor to a small footprint.

Actuating Wires
The wire that connects the horn to the points must have the appropriate stiffness. If the wire is too stiff, it can prevent the limit switch from closing. If it is too weak the points can be moved away from their end position due to bending of the wire, if the limit switch is not exactly in the correct position.





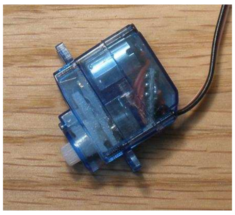
Actuating wires can be connected to the horn using this simple arrangement. Shown is 0.018" steel piano wire which will tolerate the sharp bends better than brass wire. The wire is secured to the plastic horn with CA adhesive or epoxy. CA makes a somewhat fragile bond, however. Steel wire in thicknesses of 0.014" to 0.018" provide more than enough rigidity.

It can be seen that interaction among the limit switch positioning, the length and stiffness of the actuating wire, the size of the hole through the base and the friction of the throw bar all work to provide a reliable installation. It is well worth the time to arrange these parameters correctly.

Noting all the aspects of design considered thus far, a modified design can attempt to accommodate them. Following are two similar designs, differing mainly in the size of servo motor used. Their goal is to maintain or reduce cost, require lower operating power, provide good lever positioning, enhance installation and offer a variety of operating conditions.

The descriptions should provide enough information to duplicate these mechanisms. Sources and costs are available at the end of this document.

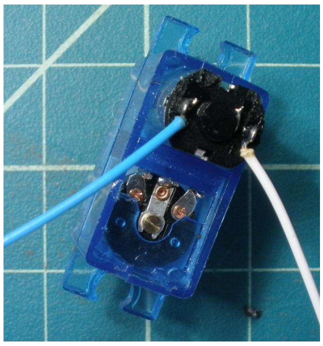
E. SG-90 Based Turnout Motor



This miniature servo measures 1.25” X 0.5” X 1.125” and weighs 0.32 oz. (9 grams). Its output torque is about 10-13 ounces but quite sufficient to move points. The high gear ratio will hold turnout points in place without power to the motor. The electronics in this servo are connected to the motor with wire leads and can easily be removed. The motor mounting is not dependent on the electronics circuit card. Motor and gear train specifications are similar to the HiTec HS-310, used in the Lomison design.

Using this motor, the dimensions of the completed turnout motor are smaller than the Lomison unit and the cost is reduced. The motor is not allowed to reach stall conditions.

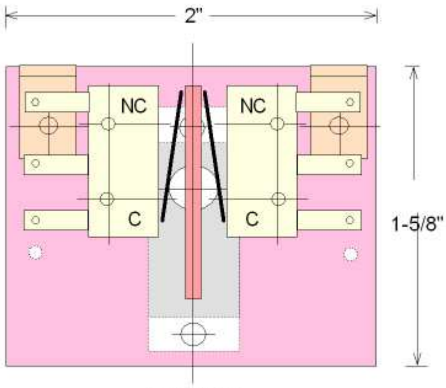
Taping the front of the motor housing to prevent gear dislodgement, the back is removed by removing four Philips head screws from the corners. The leads to the servo potentiometer and to the motor are unsoldered and discarded. Wires are connected to the motor terminals and directed to the wire grooves on the potentiometer side of the housing. The unit now appears as in the photo on the right. The back can now be re-attached.



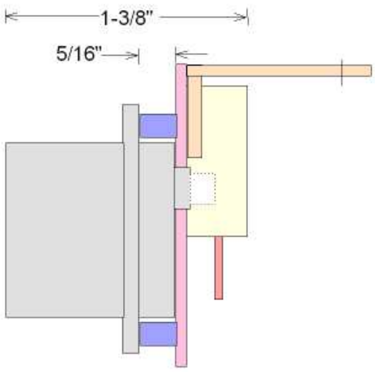
Electrical Operation

This motor begins moving at 0.5 volts DC, drawing about 30mA. The stall current at this voltage is about 120mA. Twin limit switches are employed to prevent stall conditions and to adjust the length of travel of the actuator arm.

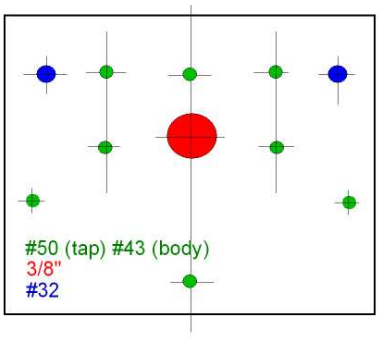
Here is the plan of this design. The drilling template can be used to fabricate this mechanism. The base material is 1/16” copper-clad circuit card. A ¼” spacer (violet) holds the servo away from the base.



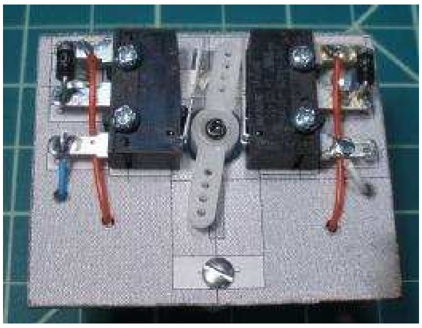
FRONT

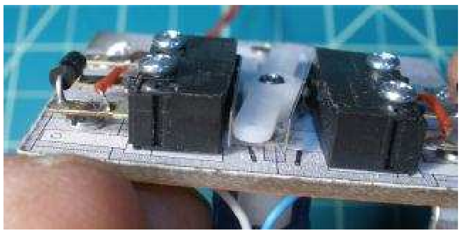


SIDE



DRILLING TEMPLATE





The limit switches in this model, from TAM Valley Depot, have an actuation pressure less than 0.4 oz.

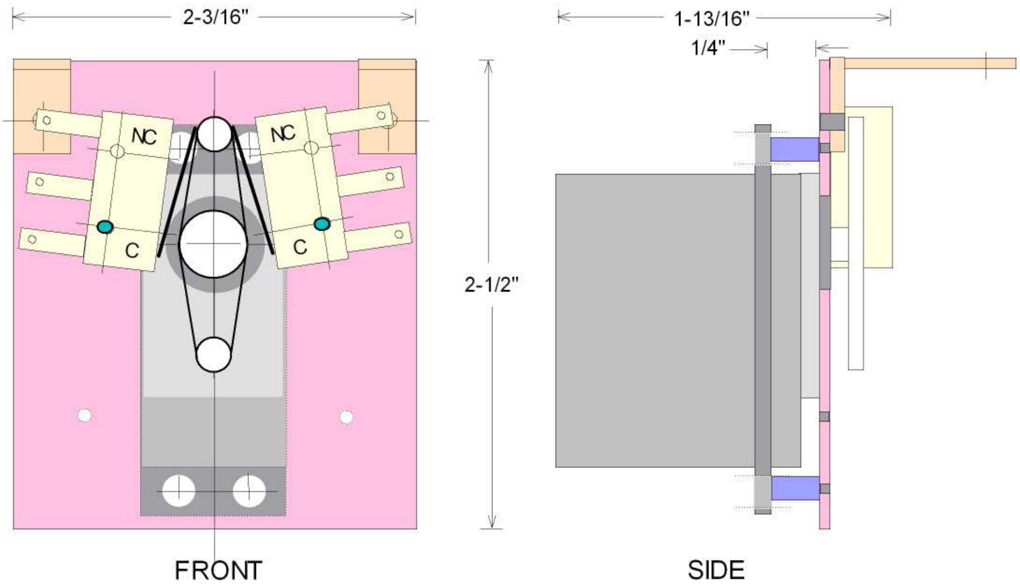
F. HS-311 Based Turnout Motor

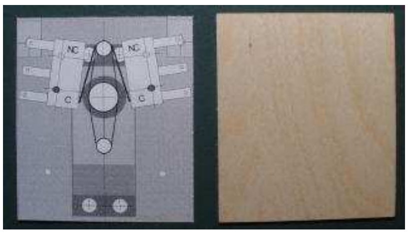
The HS-311 measures 2.08″ X 0.78 X 1.42″ and weighs 1.52 ounces (43.09 grams). Output torque is 42 oz-in. The high gear ratio will hold turnout points in place without power to the motor. The electronics in this servo and the motor are mounted on a circuit card and should not be removed. Preparation of the motor is described in Part B of this document. Before disassembling the servo, tape the top of the housing to the sides to prevent the gear train from dislodging when the back is removed.

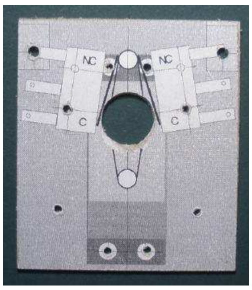
This motor also begins moving at 0.5 volts DC, drawing about 40mA. The stall current at this voltage is about 50mA. Twin limit switches are employed as before to prevent stall conditions. This time, they are shown placed at an angle to the horn and pivot on just one screw (in blue on the sketch) to adjust the length of travel of the actuator arm. Once their angle is determined, a second screw may be inserted to hold the switch firmly in place.

Here is the plan in actual size. The front view can be used as a drilling template. The large circular hole in the base where the shaft passes through is ½+″ diameter. It can be drilled using a ½″ Forstner bit then enlarged slightly with a round file. 2-56 screws and nuts were used to mount all components except the angle brackets, which used 4-40 hardware.

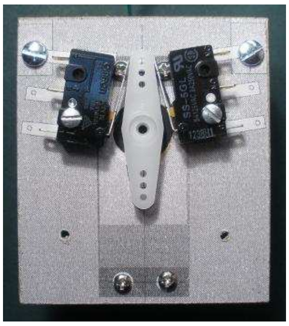
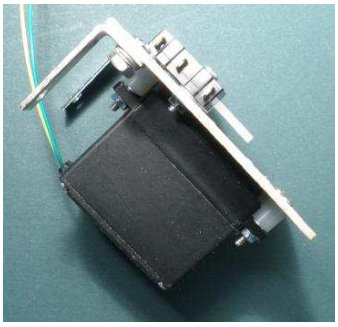
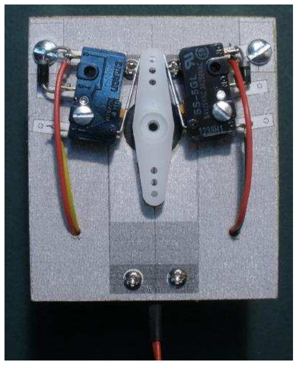
The limit switches shown in the sketch are Tam Valley, but Omron limit switches are shown in the assembled module. Their actuation pressure is slightly larger than the Tam Valley switches but, otherwise, the only difference is the length of the terminals.







The plan is cut from a printout of the sketch and mounted on 1/16″ aircraft plywood (an alternate material to the copper clad board) using rubber cement. The holes are then drilled. Mounting screws for the servo are prepared and the servo is attached to the underside of the base.

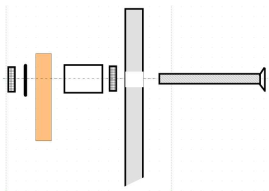
The limit switches are mounted with a single screw to allow their rotation, adjusting the horn travel to accommodate the point throw of the turnout. The photos show the unit from the front, side and completed with wiring. Note the diodes mounted directly on the limit switches.

<u>Special Considerations</u>
Creative use of spacers, screws, nuts and washers is required to provide the proper spacing between the servo housing and the underside of the base material. 2-56 pan-head screws are more than adequate for most of the mounting.

One possible exception is the top-most screw(s) that secure the servo. On the copper clad material, it is better to use a flat head screw and countersink the head. This countersink is more fragile on the plywood base because the material is less than the 1/16″ recommended but can be executed with care.

The drawings below show the hardware arrangement used in the two models for securing the servo.

SG-90

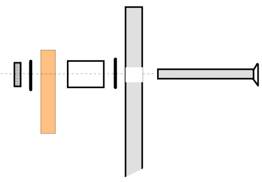


1/16″ copper-clad circuit card material (preferred)
2-56 X 5/8″ flat head screw at top (flat head or pan head at bottom)
2-56 nut
¼″ nylon spacer
Servo base
2-56 washer
2-56 nut

The limit switches are mounted against the upper surface of the base and fastened with (2) 2-56 X3/8″ screws. The through holes were tapped in this model but a nut can be used on the underside.

The brackets are attached with 4-40 screws, lockwashers and nuts.

HS-311



1/16″ aircraft plywood
2-56 X 5/8″ flat head screw at top (flat head or pan head at bottom)
2-56 washer
¼″ nylon spacer
Servo base
2-56 washer
2-56 nut

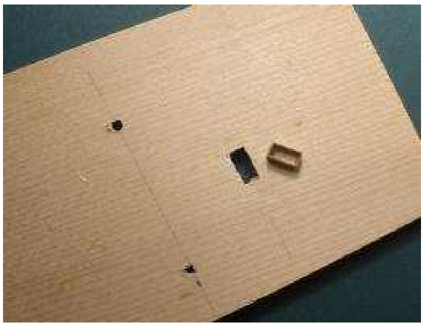
The limit switches are raised above the top of the base with 2 #2 washers. Screw length is ½″. A nut is inserted on the underside.

The brackets are attached with 4-40 screws, lockwashers and nuts.

Installation

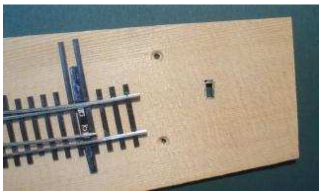
For the two mechanisms described in this paper, or for most commercial turnout machines, the mechanism should be installed as close to the turnout as possible. The installation method described here is tried and true, admittedly requiring some special attention to detail.

The turnout is mounted to a section of plywood or other suitable material whose thickness is very close to that of the track roadbed. The turnout motor is attached to this same plywood. A rectangular cutout is made in the supporting table to allow the turnout motor mechanism to fall below the track level.

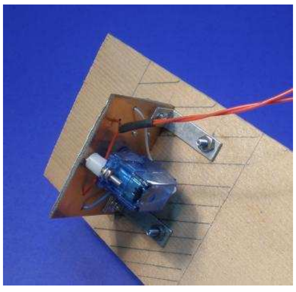


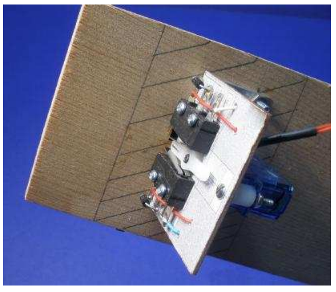
In this photo, two holes have been drilled for the mechanism brackets and one additional hole for the actuator rod. Normally the rod hole is just a round hole, about ¼ "in diameter. Here we show something a little fancier.

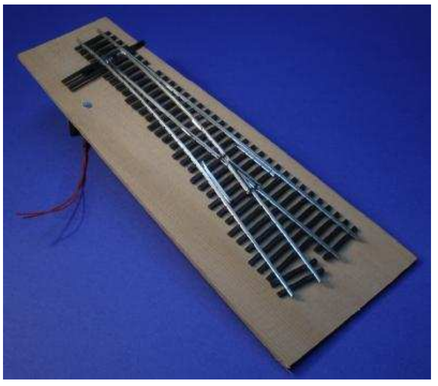
The brass rectangle is a section of K&E brass extrusion. A mating hole is cut into the plywood and the brass inserted and secured with CA adhesive. This method places the hole under the throw bar, making it invisible from the top.

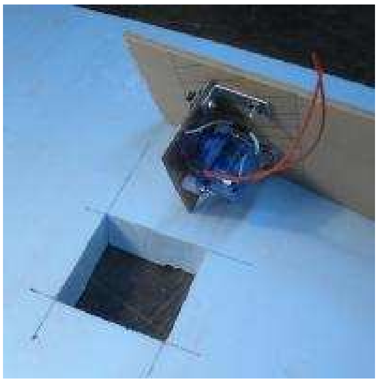


It may be that the bracket holes interfere with the placement of the turnout, in which case they can be countersunk from the top and flat head screws used to attach the mechanism. Any excess wood can be removed from the base.









This turnout motor design has been tested with On30 and smaller commercial turnouts as well as those made using Fast Tracks templates, in Code 100 through Code 55 rail. It has operated reliably even with unhinged points. If commercial turnouts are used, any locking springs on the points should be disabled, as the turnout motor does not have enough torque to overcome the spring tension. (For Peco turnouts, pushing the springs down should disengage them sufficiently.)

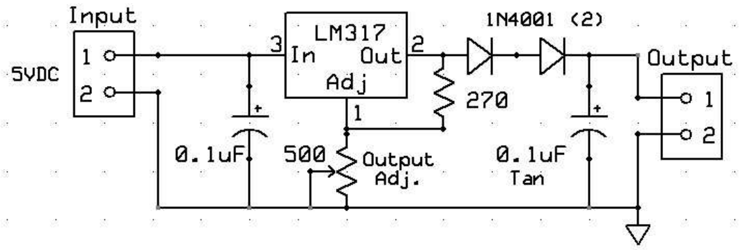
Testing has shown that the maximum vertical distance between the tip of the actuator arm and the turnout should be about ½". Distances greater than this will result in too wide an excursion of the actuator arm. In that case there is danger of not allowing the servo horn to actuate the limit switches or causing the actuator arm to backtrack, thus moving the points a small distance from their 'home' position (critical for N and HO narrow gauge scales).

H. Power

1. One D battery for a single supply or two for a double supply will easily drive a large number of turnout motors, if only one turnout is switched at a time. Otherwise, limit simultaneous switching to three units. Battery life should parallel or exceed that of batteries in a high brightness 3 volt flashlight.

2. If using Mr. Lomison's stall configuration, I suggest powering with 5 volts and using a 68 ohm, 2 watt resistor in series with the motor. For higher voltages (9 -12 volts), use 2 watt resistors of 100 ohms or 150 ohms instead of the ½ watt resistors in parallel as he suggests. (These parallel resistors get hot!) In any of these cases, you will require 100 mA for each turnout motor powered.

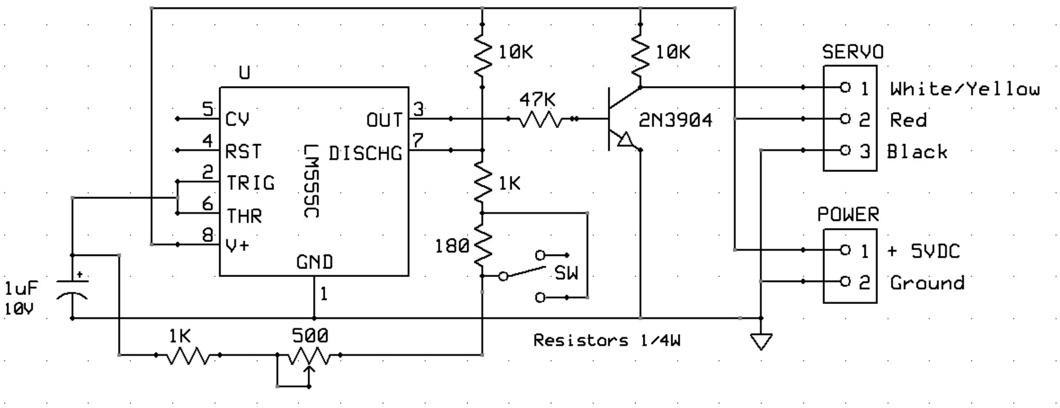
3. I know of no commercial 1.5 volt power supplies. You can build your own using this schematic. The 317 regulator will not output less than 2 volts, so a voltage drop of 1.4 volts is supplied by the series diodes on the output. The potentiometer will provide as low as 0.5 volts regulated. Maximum current drain is 1.5 amperes, enough for 15-20 turnouts operating simultaneously.



Note: This is a good supply for powering the tiny 1.5 volt incandescent lamps on the layout.

4. DC power supplies that plug into 110 volt outlets are readily available. They may be used to drive the power supply shown above, independent relay busses (5-12 volts) and provide the 9 volt or 12 volt power recommended by the Lomison mechanism.

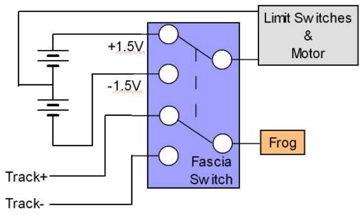
5. Servo Signal Generator. Here is the circuit used to measure servo parameters before dis-assembly.



A 555 chip is wired as an astable multivibrator to provide output pulses compatible with most hobby aircraft servos. The median pulse width is set using the potentiometer. As this is adjusted, the horn will move in proportion. By closing the switch (SW, a pushbutton) the pulse width will be changed slightly, enough to move the horn as it might in a turnout motor.

J. Auxiliary Circuits

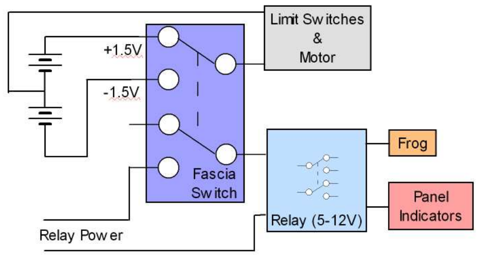
Control of frog polarity and remote indication of the turnout position are frequently required. There are a number of ways to accommodate these functions using the design in this paper.



If only frog power is required, the turnout motor can be powered from two batteries or other split supply, using only one set of DPDT contacts as shown.

The frog can be powered from the remaining contacts. This assumes the switch is located within a reasonable distance to the turnout. If not, perhaps the switch can be the slide switch type and operated remotely through a cable.

Note: It is not advised to route DCC signals over distances greater than 1 foot without using wire of 14-16 ga.



If power is also needed for panel indicator lights, then the extra set of switch contacts can power a DPDT relay from a separate supply. This allows one set of relay contacts for the frog and another for the panel indicators.

It is possible to draw indicator power directly from frog power in DCC systems using a full wave rectifier and suitable LED resistors. It is not firmly established whether or not such a connection to the DCC lines is harmful to some DCC accessories, however.

K. Sources

The principle ingredients of the two modules cost between $10.00 and $15.00. However the 'bits and pieces' can add a significant amount, as do shipping costs. It's worth trying to locate what you need from as few suppliers as possible. Jameco and Mouser will sell and ship small orders with only a few items. Radio Shack parts will be more expensive. You can also look for significant discounts on servos but be sure they include the horn package.

Hardware
2-56 and 4-40 Screws, Nuts, Washers. Micro Fasteners Inc. www.microfasteners.com

Note: Also see www.smallparts.com. A site worth visiting!

Brackets. Keystone. Mouser P/N 534-620 $0.31 each www.mouser.com
Spacers. Nylon #4, ¼" Mouser P/N 561-KSP6 $0.24 each

Module Mounting Material
Copper clad board. Radio Shack, Mouser, Jameco #169288, 6"X6". $3.95.
Aircraft plywood. Hobby stores, Michael's.

Power Supplies
Battery holders. Radio Shack, Jameco # 216390 (dual) $1.19, #216371 (single) $0.69.
Wall mount, 5-12 VDC. All Electronics, www.allelectronics.com. A wide selection at good prices.

Relays, DPDT
I recommend using 5 or 12 volt miniature relays if possible.
Omron G5V-2-DC5, -DC12. Mouser, Jameco

Servos
HiTec HS-311, $7.99, Tower Hobbies. www.towerhobbies.com. Torque 42-49 oz/in. Alternate: Futaba S3004 $13.99 Torque 44-56 oz/in.

SG-90. $4.95, P/N SRV002, Tam Valley Depot (www.tamvalleydepot.com). Torque 10-13 oz/in. This part is sometimes drastically discounted on the Internet. Alternate: HiTec HS-55 $10.99. Torque 15-18 oz/in.

Switches
Limit Switches

SG-90 unit: TAM Valley Depot, P/N SSW001. $3.00, package of 4
HS-311 unit: Jameco-Omron, www.jameco.com, P/N 187709. $1.50 each.

Note: The Tam Valley switch can be used with any servo. Lever switches from discount houses are there because they are discontinued or have failed quality control, usually actuation force. The switches above have been tested for low pressures and are highly recommended.

Toggle Switches

SPDT. Radio Shack, Jameco, All Electronics, Mouser
DPDT. Radio Shack, Jameco, All Electronics, Mouser

Wire
(I disassemble 6-wire cable used for telephone and network connections. Gauges 34-28 are acceptable.]

References
Hopkins, Gerry. "Using servo turnout motors." (With electronics only)
http://www.nmra.org.au/Hints/Servo/servo.html

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