Development of a Short Travel, Rack and Pinion, Servo Mount incorporating Hall Effect sensors for position monitoring.

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Abstract

This article describes the development of a 3D printed, linear travel servo mount that uses a geared down rack and pinion drive. The gearing enables finer adjustment of the operating positions for use in switches from 2 mm FS to O gauge. The mount also incorporates a method of using one or two Hall Effect sensors and neodymium magnets to monitor the tie bar position. The mount is compact and quite robust and at less than 25mm deep is not as susceptible to damage as some mounts are when fitted under the baseboard. There is also some discussion of interaction between JMRI Layout Editor panels and a CBUS control panel.

Introduction

The development of this servo mount has come about due to a number of factors that happened in just the right order. The first was a need to create a demo board to get to grips with CBUS and JMRI. The board was basically a plank with a headshunt and three sidings, so two servo mounts were required to operate the points. As I intended to have all the wiring on top of the board, the servos would also be top mounted. I bought kits 681 and 682 and found these to be quite fragile. I had to replace them after slightly careless handing of the board when carrying it cracked the mount at the bottom. The height of the mount is quite a disadvantage as any slight force at the top creates quite a bending moment at the base of the mount that can cause it to crack. As I had six mounts initially and only two places to put them, this would not be a problem unless I was careless when handling it again. At that stage I wasn't interested in fitting micro switches as I wasn't looking for position feedback and the EzyRemotePCB board I designed had a relay for changing the crossing polarity.

The second factor was that I had a notion to get a 3D printer as I could see the potential for producing all manner of items for a layout. As a civil engineer, I could see possibilities of plate girder bridges, truss bridges, buildings, station roofs, concrete cable ducts, equipment cabinets, switch motors and a whole host of other things. As I had taught the use of AutoCAD to create 3D structural models, I had that skill as a basis to work with in creating models.

The third factor was a Forum conversation with Hugo Fitzjohn regarding an adaptation of my EzyRemotePCB firmware led Hugo sending me some parts he had printed for his servo driven uncoupler (merg.org.uk/s/3d-uncoupler). The spring activating part he had designed had to be fixed to a standard servo horn with tiny screws (figure 1). That seemed unnecessary to me as I thought surely it must be possible to design that part in such a way that it had the splined boss at the end for direct fitting to the servo. With a 10X lens and good lighting I counted the splines inside the horn and after many attempts decided that there were 21 of them. They weren't really splines as such, but a series of triangular projections between two circumferences (figure 2). The outer I could measure reasonably well on the servo shaft with my Aldi Vernier gauge but the depth of the projection to the inner I had to guess. I modelled this in AutoCAD, produced the STL file,

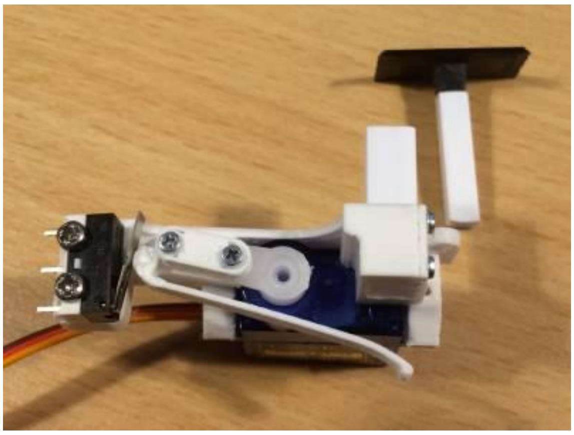

Figure 1: Hugo Fitzjohn's uncoupler mount

Figure 2: Splines inside servo horn

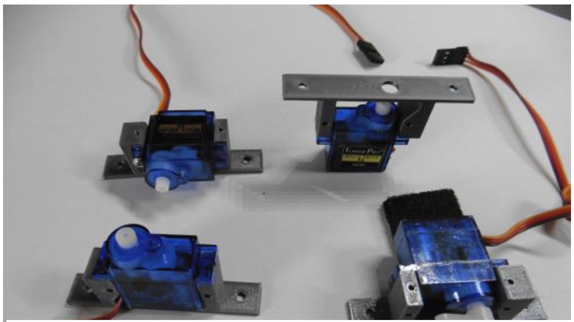

Figure 3: Universal servo mount, original version

imported it into Slic3r, exported the G-code file and printed one. A bit of fiddling with sizes produced a hub that fitted snugly on to the servo shaft

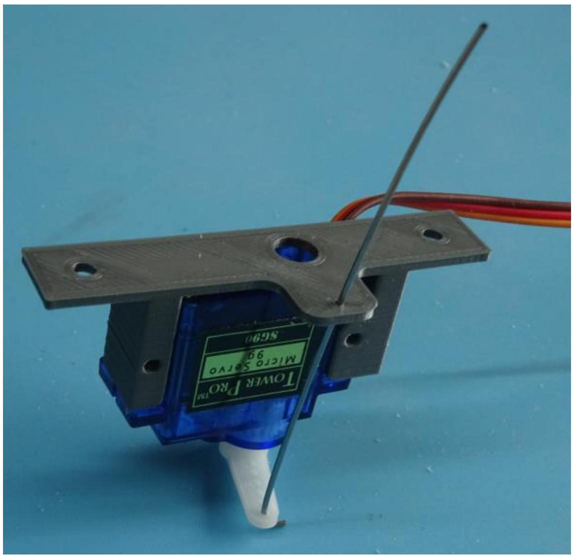

Figure 4: Universal servo mount, version two

The final factor was that by this time, I had looked at several servo mounts of various forms. I had designed a couple of simple mounts, one of which could hold the servo in various positions for above and below board mounting (figure 3). I revised the design to include a pivot point for a tie bar operating wire and this has proved to be very popular with WoSAG members (figure 4). I shared the STL files with other members and apparently several hundred of these have since been sold at WOSAG meetings. In many cases with these and other designs of mount, these used a wire that rotated in the vertical plane and stuck out through the point tie bar more at the mid position than at the ends of its travel. Different thickness base boards are also a problem for this type as the movement at the top surface is increased as the base board becomes thicker. This means less rotation of the servo to produce the required movement, so making adjustment of the operating positions coarser. Other servos were providing a linear movement by using a spigot in a slot, with the spigot being rotated by the horn to give a non-uniform rate of movement. What I wanted to produce was a linear, uniform motion. The obvious (to me anyway) conclusion was to use a rack and pinion arrangement.

Mk 1 mount

Gears are complex geometrical items and to work properly they must have exactly the right shape to allow the two sets of gear teeth to roll over each other. They are not simple to draw so I investigated the internet to find a source of information to allow me to make gears. One of the sites I found, Involute Spur Gear Builder (http://hessmer.org/gears/InvoluteSpurGearBuilder.html), provided an online calculator that gave a simple but effective way of generating DXF files of the gears that could be imported into AutoCAD and converted into a 3D object. There is also a link on that page to a standalone version by Doug Rogers (http://dougrogers.blogspot.com/2016/08/gear-bakery-10-port-of-dr-rainer.html) that I downloaded and used in preference to the online version. They both can be used to create regular gears, rack and pinion gears and internal gears as used in epicyclic systems.

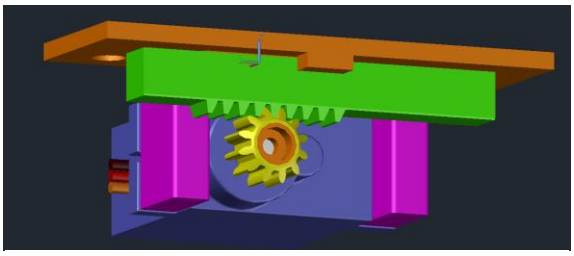

Figure 5: AutoCAD model of Mk1 rack and pinion mount

Racks are different from other gears in that the tooth shape is straight sided. With this program, I was able to investigate different gear pitches and numbers of teeth. To get a sensible movement in the rack for points, the working diameter needed to be quite small. I found that a 2 mm pitch, 12 tooth (12T) cog, was reasonably satisfactory as that would give 6 mm movement with a 90° rotation of the servo and obviously 12 mm travel if 180° rotation was used. The rack needed a minimum tooth count of six so they were made with nine teeth (figure 5). I tried an 11T cog to reduce the travel but the small diameter of the base of the teeth combined with the diameter of the recess for the fixing screw meant that the teeth were separated from each other so that idea was shelved. I made a few of these 12T mounts and installed two of them on my demo board to change the points. As the mounts were above the baseboard, I simply used a horizontal piece of piano wire through a hole drilled in the rack, doglegging down below the track and running in a channel to the centre of the point tie bar (figure 6). From this idea I decided to form holes at both ends of the rack

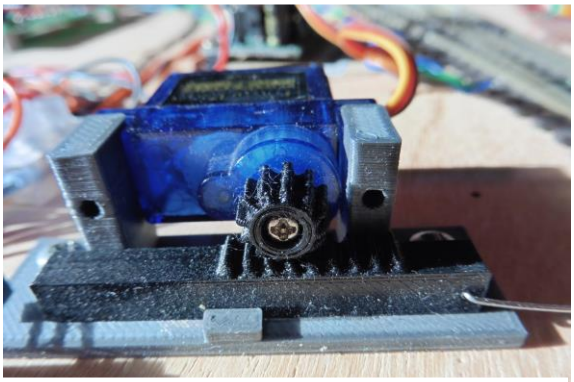

Figure 6: Prototype Mk1 rack and pinion mount

to allow this method of connection. For normal, below baseboard mounting, I provided a hole in the top of the rack that would take a vertical piece of piano wire to come up through the tie bar.

Davy Dick had asked me to take my board along to the WOSAG Open Day in 2018 so that I could show CBUS in action and there was quite a bit of interest in the new mounts. For one thing it is quite low profile so that it is far less likely that they would be knocked or pushed. They were also quite rugged so that even if they did get a nudge they were very unlikely to break.

Long travel mount

After my attempts to get a small movement of the rack, I was quite surprised to get a request for a long travel rack of between 25 and 30 mm. These were to be used for operating coal chutes and a loading ramp for a car ferry. For this I used a 2 mm pitch, 30T pinion that with 180° rotation would give 30 mm of travel (figure 7). I had to increase the length of the support posts of the mount to accommodate the bigger pinion and make the slot in the base longer to deal with the increased travel. During a conversation with the member who wanted these items, he mentioned that he was cutting bits off the mount to get them to fit in a particular situation, so I offered to remove the bit from my model and print some new ones for him.

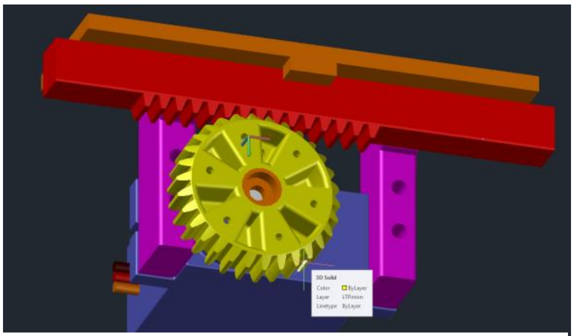

Figure 7: AutoCAD model of long travel mount

Short travel mount

At this stage, development work slowed down considerably as I took on the role of Journal Editor. There were also things I wanted to do with the demo board to improve its performance and usefulness as a learning aid for CBUS and DCC at the next WOSAG Open Day.

I had realised from various conversations with members that what was needed was a mount that would give good resolution over a limited travel for the likes of those modelling in P4 and 2 mm FS but still able to be used for typical 00 trackwork like Peco. To make that work would require some form of gearing. I looked at an epicyclic system with the drive to the sun wheel with a stationary ring gear and the output taken from the planets (figure 8). To get a significant reduction required quite a large outer ring. It proved to be too big to be acceptable and really too complicated for printing and assembly.

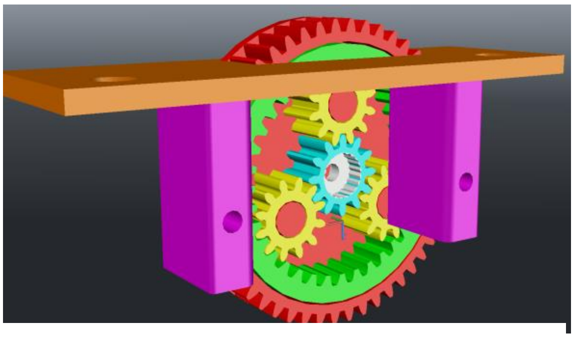

Figure 8: AutoCAD model of epicyclic gears

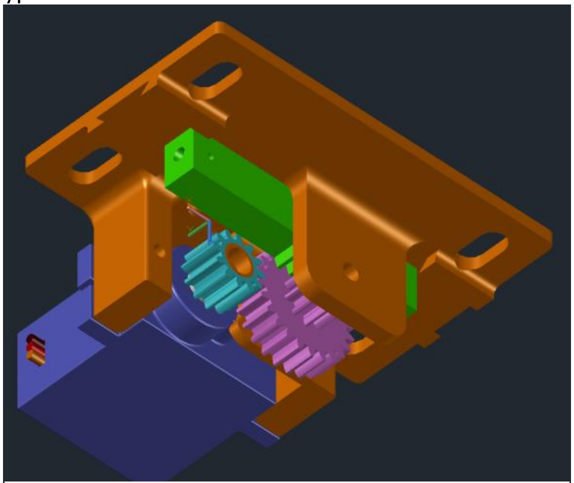

Figure 9: AutoCAD model of current version

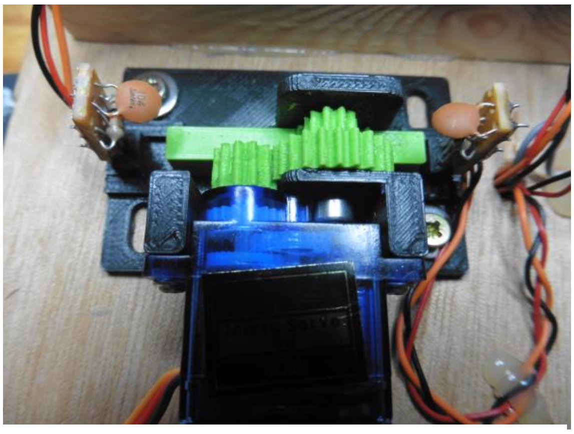

Figure 10: Prototype of current version

Eventually, I decided on a 12T to 24T reduction gear then a 10T output pinion to the rack (figure 9). I increased the depth of the rack to accommodate the 24T gear and increased the length of the servo support posts to suit. Initially I printed a 4 mm diameter shaft for the gear combination, but after I broke it trying to remove it, I decided to use a 3 mm diameter steel bolt. There were several modifications needed to the "gearbox" to allow everything to go together properly and easily but in the end it all came together. With the reduction, a 90° rotation gives 2.5 mm travel and 5 mm travel with 180° rotation (figure 10).

As in the Mk 1 mount, I have provided a hole in the top of the rack for a piece of piano wire to operate the tie bar. A conversation with a member of the P4 society on an adjacent stand at the Perth Model Railway Show in June led to a suggestion to provide two holes, 9 mm either side of the central one to take a piece of small diameter brass tube into which could go a small diameter piano wire that would be soldered individually to the switch blades. Further thought has suggested two holes at 4 mm either side of centre to cater for 2 mm FS modellers

Switch position indicator(s)

As noted above, my DCC/CBUS demo board has two points, it is sectioned in to six blocks and these are monitored, via my TwinToti units, with an old CANACE8C module. The track occupancy detectors use six of the CANACE8C inputs so two were spare. I controlled the points and showed the track occupancy using JMRI but what I also wanted to do was to be able to control the points manually via a mimic panel. For that to happen I needed to have some form of point position detection.

By default, JMRI uses direct feedback with points, i.e. it assumes that if a point has been told to move then it will have done that. It can also work with a single on/off detector or two detectors that go on when the switch blades reach their end of travel. With just two spare inputs I had to use the single detector method but what method could I use? The obvious choice was a microswitch but then a Journal article submission by Tony Chamberlain using Hall Effect sensors to identify locos suggested to me that there might be another option.

The type of sensor that Tony used gives a variable output depending on polarity of the magnet and its distance to the sensor but that would have needed some circuitry to create an on/off output. Then I remembered that at the bottom of the PMP page in the kitlocker there were Hall Effect sensors listed and found that these (PMP99) were of the on/off type. I purchased a pack of these and also some 2 mm diameter x 1 mm thick neodymium magnets from first4magnets (first4magnets.com).

To use these, I drilled a 2 mm diameter hole in the end of the rack for the magnet and built a small stripboard circuit to take the Hall sensor, resistor and capacitor. The resistor used was a 1k between output and +5 V and the capacitor was a 100 nF between 5 V and 0 V. The top pin of the sensor in the photo below is my +5 V, the next is 0 V and the bottom is the output. Note that the narrow face of the DRV5033 with the splayed faces either side is towards the rack. I then had to find a way to mount the circuit. My good friend hot melt glue provided a simple solution and after a bit of testing to see where the switching point occurred, the circuit was glued into place (figure 11). Fine adjustment was obtained by judicious bending of the sensor legs.

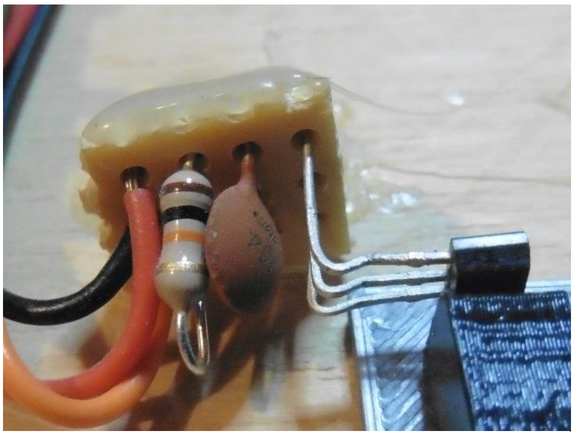
Figure 11: Prototype of Hall Effect stripboard circuit

A CANPAN module in my mimic panel monitors the pushbuttons and then activates the servos via CBUS to a CANACC8 module. As the servos move between their set positions, the Hall Effect sensor turns on or off and that effect is picked up by the CANACE8C and that sends a message to the CANPAN to light the LED on the leg set and extinguish the LED on the other leg. JMRI also picks up the messages about the state of the position sensors and indicates the correct direction on the on-screen panel. As a result, I am now able to change the points via JMRI and have the result shown on my mimic panel or change them on the mimic panel and have the results show on the JMRI screen. Of course, both work as expected if used alone.

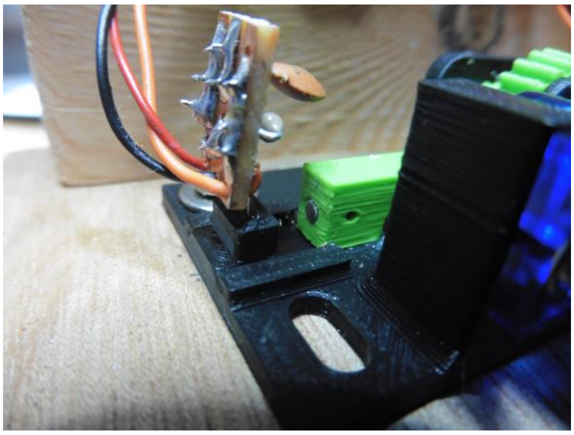

Figure 12: Modified Hall Effect stripboard circuit in adjustable holder and neodymium magnet in end of rack

In transferring the idea of Hall sensors to my short travel rack and pinion servo mount I have made a few changes to make the installation and adjustment of the sensors much easier. The rack is now able to be shorter as the travel has been reduced. With that shortening, it is now possible to provide holders for the Hall sensors on the mount base (figure 12). Note that is sensors, as there is provision for a sensor at each end of the rack to give three state positioning: fully normal, fully reverse or indeterminate. The holders are retained by a dovetail groove that allows adjustment of their position. Holes have been formed in the ends of the rack for installation of the magnets and these align with the centre of the Hall sensor once installed in the holders. The magnets should stay in place by themselves or they can be held by a spot of superglue. As shown in figure 13, a simple 5 x 3 piece of strip board is used for mounting the sensor, resistor and capacitor with the sensor fixed into the holder with a drop of super glue. Easy setting of the holders can be achieved by setting them tight to the ends of the rack and then operating the servo to push the holders outwards. Unless an extremely short travel is set then the sensors should work fine in that position but if a more sensitive operation of the sensors is required i.e. operating only at the very end of rack travel, then they can be moved out a bit more with the aid of a flat bladed screw driver between rack and holder. Once they are in the correct position they can be fixed with a drop of superglue or hot melt or a blob of blu or blacktack.

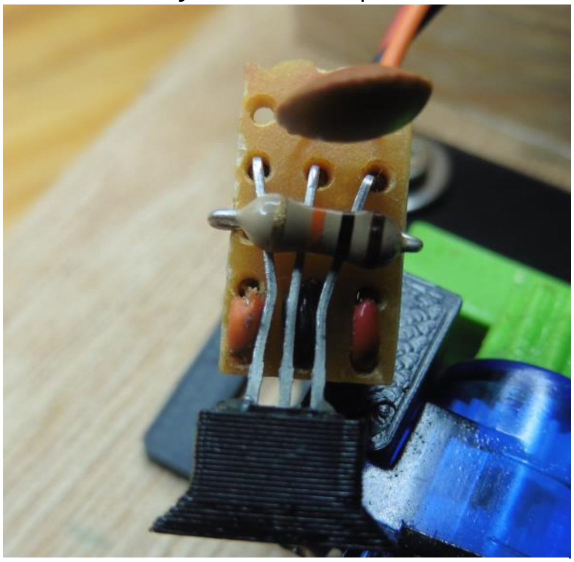

Figure 13: Minimal Hall Effect stripboard circuit fixed into holder

Future work

I have now acquired a few of the standard MERG micro switches and I will be looking to make an adaptation of the Hall sensor holder to carry a micro switch to give a cheaper option of monitoring the tie bar position. I may also look at a mounting for micro switches for the Mk1 rack and pinion mount.

Conclusion

The goal of designing a servo mount to give fine adjustment for use with small travel switch blades as used in P4 and 2 mm FS trackwork has been achieved. It is also suitable for N, 00 and even 0 trackwork. An additional feature to permit monitoring of the tie bar position using single or twin Hall Effect sensors has also been incorporated. The mount is low profile and robust so should be much less prone to damage than some other designs of mount. The STL files used for the simple Mk1 mount can be found at merg.org.uk/s/r&p_servo_mount and those for the short travel mount can be found at merg.org.uk/s/short_travel_servo_mount.