Non-twisting Cable Braider

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A non-twisting cable braider was designed for braiding the signal cables for the LEGEND experiment, which requires very low-noise signal transmission. The area between cables acts as an antenna, picking up noise proportional to the area enclosed by the cables from ambient electromagnetic radiation. Two methods of reducing pickup noise used by LEGEND are braiding cables and shielding cables. By braiding the cables alternating loops are formed, which will have alternating polarity of pickup noise from loop to loop. This causes significant cancellation of pickup noise. Smaller loops formed by twisting the cable tighter tends to provide better noise reduction, and has the added benefit of producing an easier to handle cable bundle. Shielding the signal conductor with a grounded shield also reduces pickup noise, but there is always some noise that makes it through the shield—especially at low frequency where the skin depth is longer than shield thickness. In bundles of shielded cables, the shields themselves also become antenna loops and this pickup can be mitigated by braiding the cables. LEGEND is testing braided bundles of individually shielded coaxial cables.

The LEGEND cable braider uses spools on carriages that are moved around a track by horn gears. As it is weaved the finished cable is wound on another spool, and the relative speed at which the cable is wound compared to how frequently the spool carriages move around the track controls the braid pitch. Cable braiders employing spools being moved around a track by horn gears have been used for more than a century. The most popular type is a maypole pattern, formed by two groups of cable carriers moving in opposite directions around a rough circle. The carriers switch between the inside and outside track to weave a tube around the center. Another method is to pass pairs of cables through the center of the cable braid, cycling through pairs of cables. Such a design was patented in 1989 under US patent 4803909. When braiding only four cables, such as will be done for LEGEND, this pattern is identical to a maypole braiding pattern. If additional spools are added to the LEGEND braider it will closely resemble the 1989 design, but with a key improvement to preventing twisting the cables. Braiding the LEGEND signal cables on a machine similar to the 1989 style of braiding machine resulted in either braids with too long a braid pitch to be easily handled, or kinks in the braided cable as shown in figure 3.

As the spools are moved around the track they rotate one revolution per

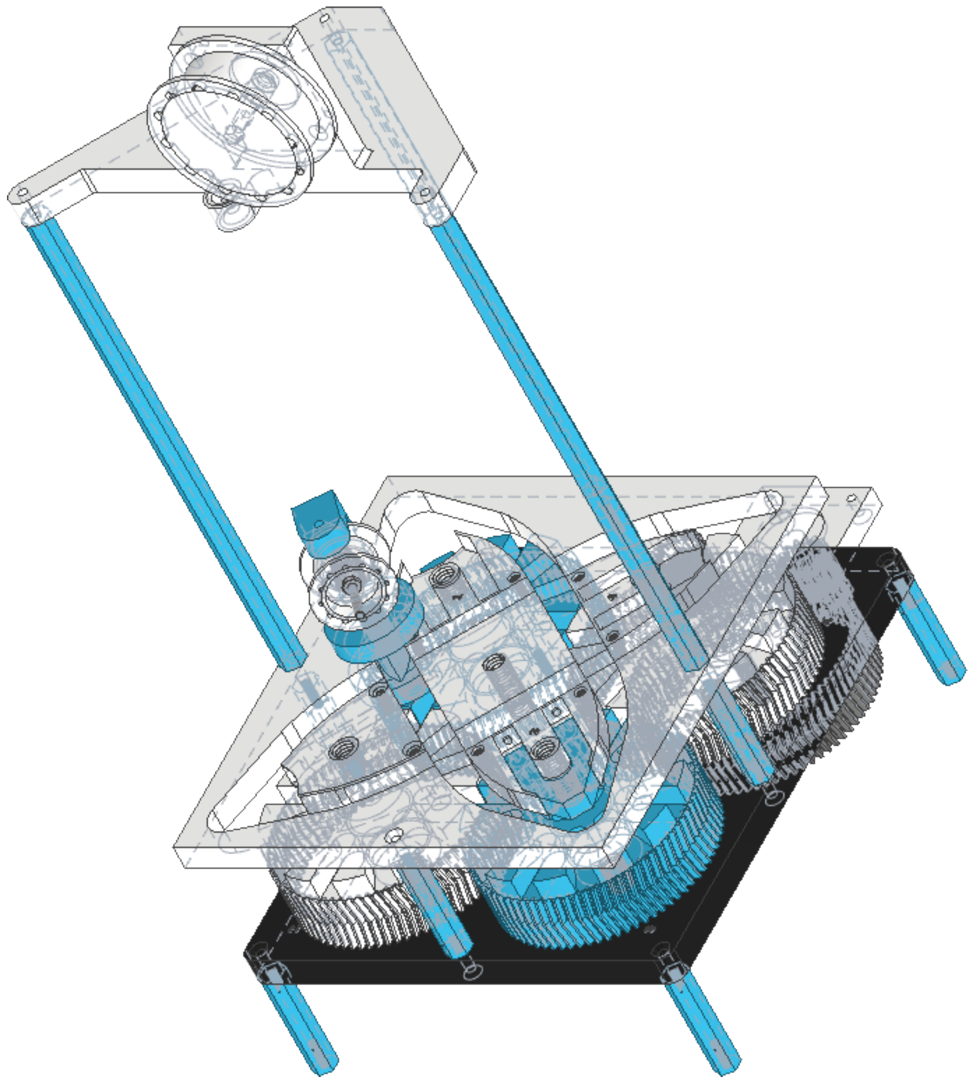

Figure 1: Non-twisting cable braider. Shown with one spool assembly, one spring tip on the lower right, and one tip cover on the lower left. Shafts, springs, motors, and most fasteners not shown.

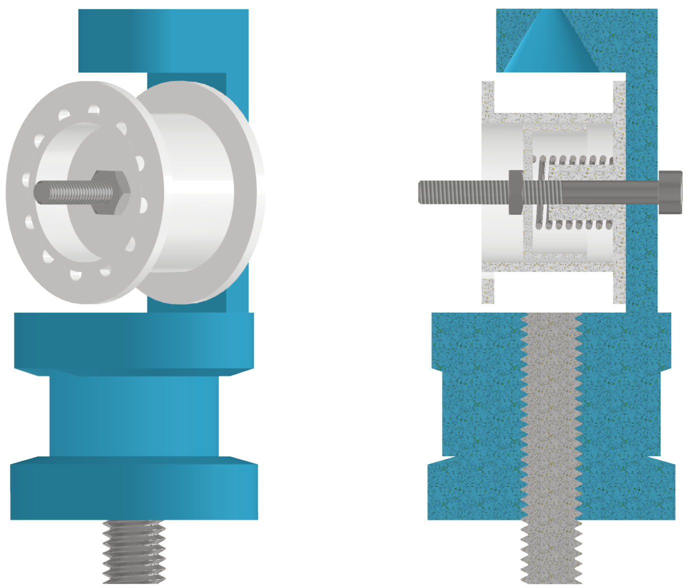

Figure 2: A spool assembly, half section view on the right. Cable is wound around the spool and the free end is threaded through the hole in the top of the spool holder. The spool rotates around a horizontal axle, this way no twisting of the cable occurs from unwinding the cable from the spool. The spring around the spool axle held by a bushing positioned by a lock nut applies force on the spool against the rising arm of the spool holder. Moving the lock nut adjusts the tension of the spool to prevent it from unwinding freely. An alternate design with a rewinder was considered to take up slack as the spool traveled through the central area of the track, but the slack didn't cause any issues so this simple friction clutch was used.

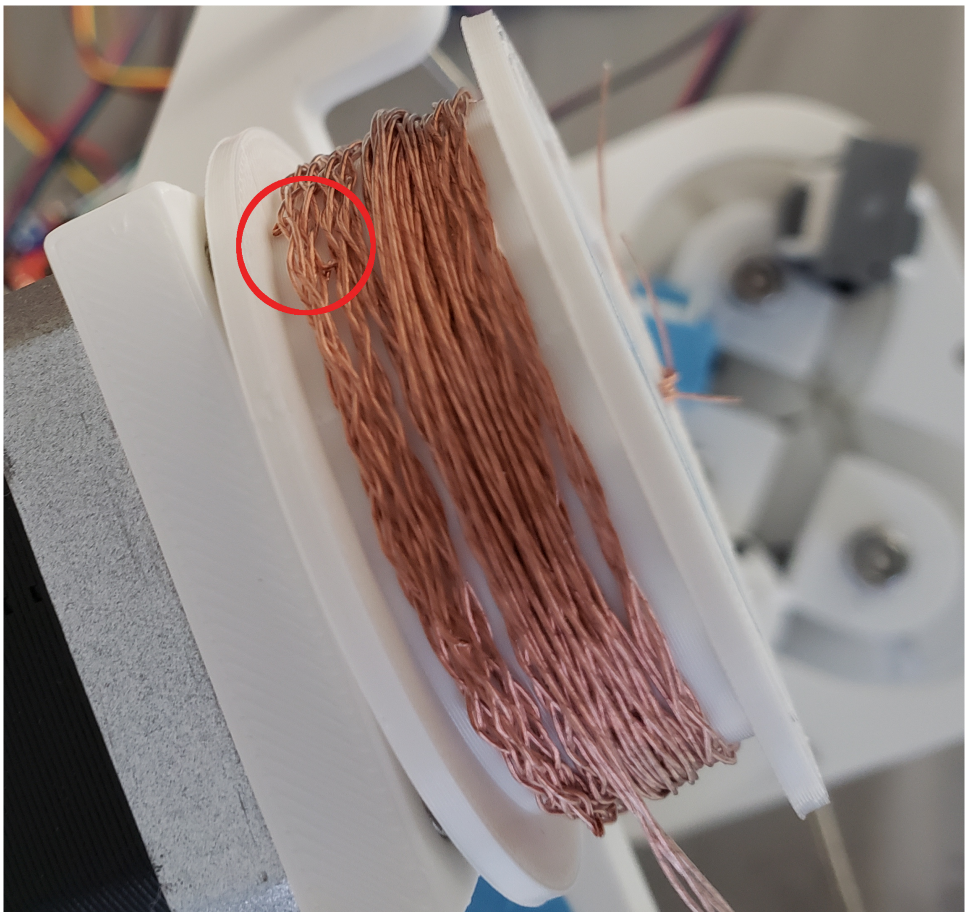

Figure 3: Kinks occurred when tightly braiding the LEGEND signal cables using a braiding machine that would twist the cables. Two such kinks are circled in red. Also shown on the spool is a section of cable that was braided with a longer braid pitch. While the longer braid pitch prevented kinks, the cable was difficult to handle.

trip around the track, twisting the cable once. This can be compensated for by taking the cable off the end results in one twist per loop removed from the spool. If the spools are wound such that the twist from cable coming off the spool cancels the twist from traversing the track there is no resulting twist in the cable. However, this requires the circumference of the spool matches the braid pitch. This would require a tightly wound spool for a tight cable braid, limiting the braid pitch by the minimum bending radius of the cable. This approach to eliminating cable twisting was unsuitable for attaining the high braid pitch desired for LEGEND.

To achieve a high braid pitch two improvements were made to the cable braider over the initial design.

Most importantly, the spools were oriented so cable was taken from the side instead of the end, so that there was no twisting induced by unwinding the cable from the spool (see figure 2). The track was redesigned to compensate for rotation of the spool as it traveled around the track (see figure 4). This counter rotation was induced by recesses added to the track. The recesses would catch the carriage guides and rotate the spools to compensate for the rotation due to movement around the track. Adding a retractable part of the track that the guide can push aside was found most effective, but rotation can be induced using a fixed track with only recesses.

The second improvement was to shift the position of the spool carriages on the horn gears. In the previous design the slots in the horn gears were symmetric, causing two spools to be in the same position on opposite sides of the track. The carriages experience some positions of higher resistance, the most noticeable for the non-twisting cable braider is when pushing on the retractable track section. By shifting the spool positions (see figure 6) the machine only has to push a spool carriage through these difficult points one at a time instead of two at a time, reducing the torque required by the motor and allowing the machine to run faster. Breaking the symmetry of the track would have accomplished this as well but would have been more complicated.

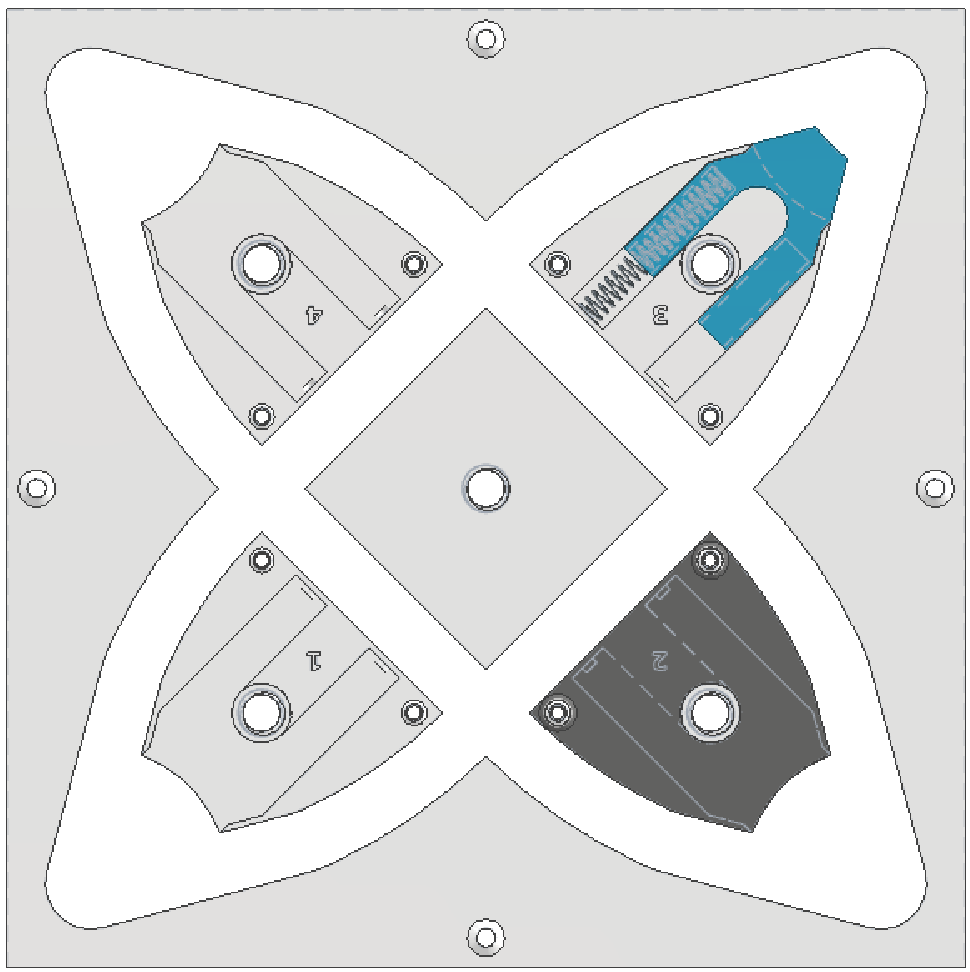

Figure 4: Track with rotation countering recesses at turning points. Only one of the spring-loaded retractable tips is shown in blue in the upper right, and only one cover is shown installed in gray in the lower right.

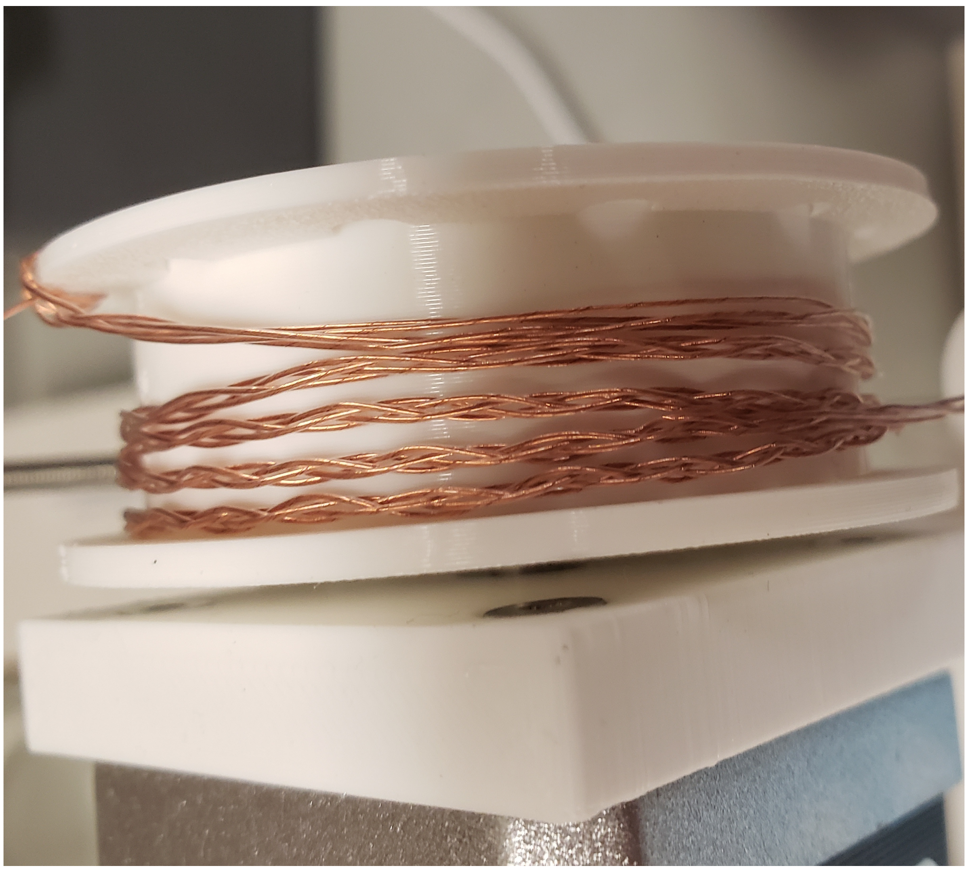

Figure 5: The same cable as in figure3 rebraided with the non-twisting cable braider.

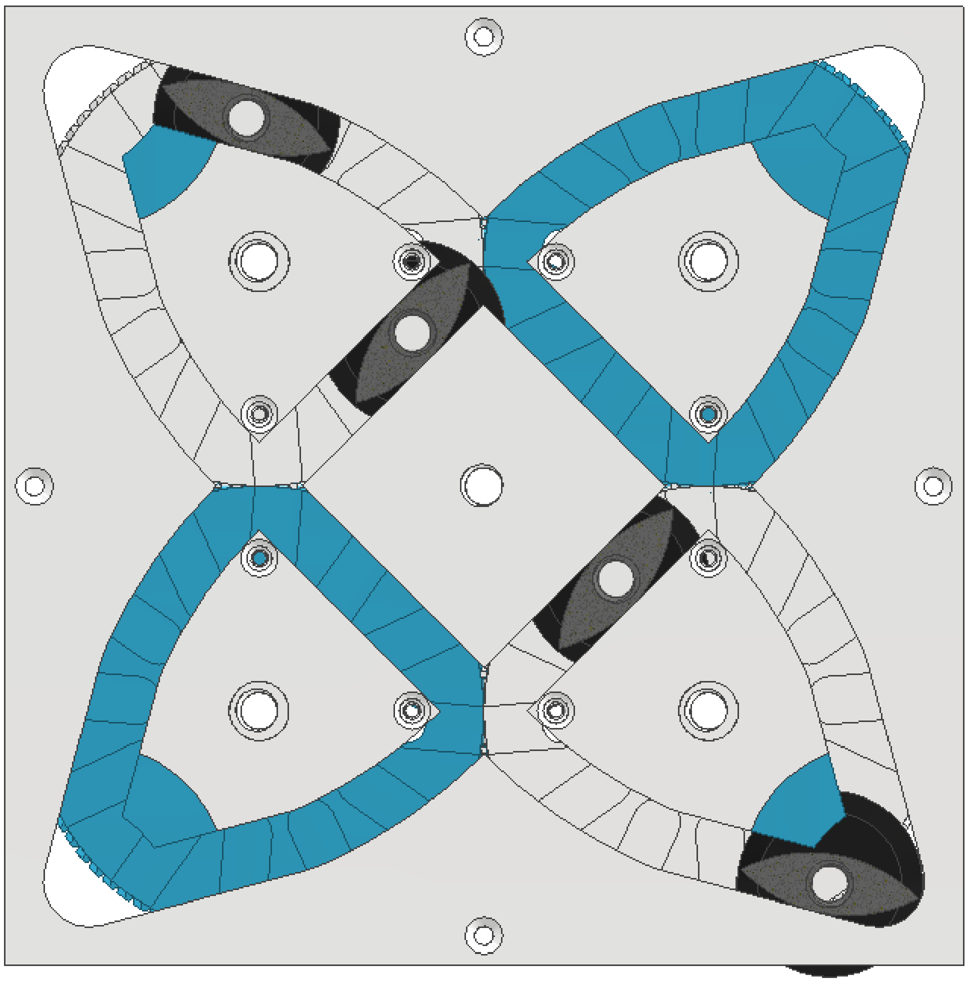

Figure 6: Additional slots were added to the horn gears to allow offsetting the spools, so no more than one spool at a time passed the same problem point in the track. Preventing two spools from passing the rotation compensating corners at the same time is most important, as that is the highest resistance point in the movement. The carriage guide portion of the spool assemblies are shown in gray.