Gears and Periodic Errors

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Most modern mounts use a worm-and-gear (also called worm-and-wheel) type of drive on each axis. These allow for a full 360-degrees of rotation, non-reversibility of the drive, along with a great amount of gear reduction.

The reduction in a worm-and-gear drive is dictated by the number of teeth in the driven gear. A 360-tooth gear will show 360:1 reduction while a 180-tooth gear will have a reduction of 180:1. As in the transmission of a car in low gear, motor torque is greatly multiplied by low gear ratios, allowing a small motor to easily turn a large and heavy telescope. A telescope has to be able to track the sky accurately at approximately one revolution per day, but a motor alone could not turn accurately at a speed that slow. The large amount of reduction in a worm drive allows the motor to turn at a usable speed while keeping the tracking rate slow.

Figure 1 shows the worm and gear setup from a Mathis Instruments mount. The worm is the small steel *driving* gear and the worm gear is the large bronze *driven* gear. Due to the non-reversibility of the gears, the worm gear cannot drive the worm, which is perfect for telescope use (and also why they're used in guitar tuners). This means that when the drive is stopped, even an out-of-balance condition will not cause the axis to slip unless the clutch is loose or a gear actually strips.

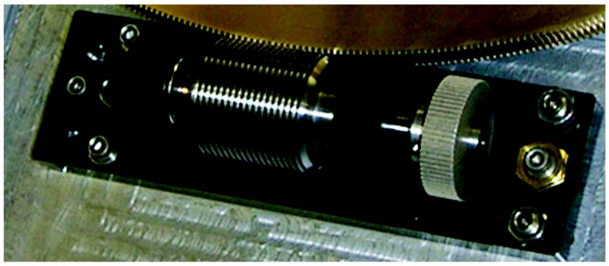

Figure 1 — Worm and gear from a Mathis Instruments mounting.

A favourite discussion in the on-line forums is the topic of periodic error (PE)—a tracking error caused by slight inaccuracies in the mount's RA worm. This makes the mount speed up and slow down very slightly through each rotation of the worm in a repeatable fashion; hence the term "periodic." The change in speed causes a target to wobble back and forth in right ascension as shown in Figure 2.

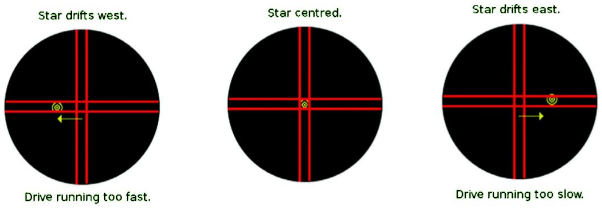

Figure 2 — Crosshair-view images of periodic error in Right Ascension

PE can be caused by many different types of inaccuracies in the worm. Figure 3 shows two worms that have machining errors compared to one that is perfect (left graphic). The centre worm itself is round but is being driven off centre which will cause it to strike the gear alternatively closer and further from the centre of the gear's rotation. The graphic on the right is a worm that is out-of-round, or egg-shaped.

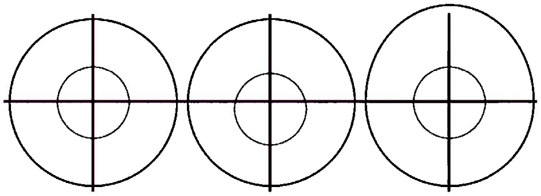

Figure 3 — A schematic of a normal gear construction (left) and two machining errors (centre, eccentricity; right, oval-shaped worm gear) that will affect tracking.

Both of these types of machining errors will cause the mount's RA axis to speed up and slow down alternately with the period of the worm.

A greater problem is a worm that is "bumpy", as is shown in Figure 4. The left hand example shows a smooth worm (red) striking the gear (black). As the worm turns it will turn the gear smoothly. The right side of the graphic shows a poorly polished or lapped worm striking the gear. This will cause the gear to jerk quickly while turning, either speeding up or slowing down rapidly with a period much shorter than a full worm rotation.

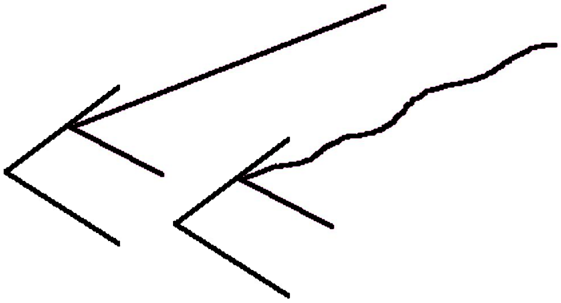

Figure 4 — schematic showing smooth (left) and bumpy gears; the first will give few tracking errors while the latter will have a very uneven periodic error.

Figure 5 shows the actual PE curve of a modern popular German equatorial mount with a peak-to-valley amplitude of about 26 arcseconds. This sounds like a lot but is not unheard of with today's telescopes. The PE curve is superimposed on a perfect sine curve that shows that the mount's gears are quite smooth. The spikes are most likely due to seeing. The important thing in the graph is not the amount of PE but that the curve almost perfectly matches the sine curve. On this mount, an auto-guider will be able to correct perfectly any drift in a guide-star.

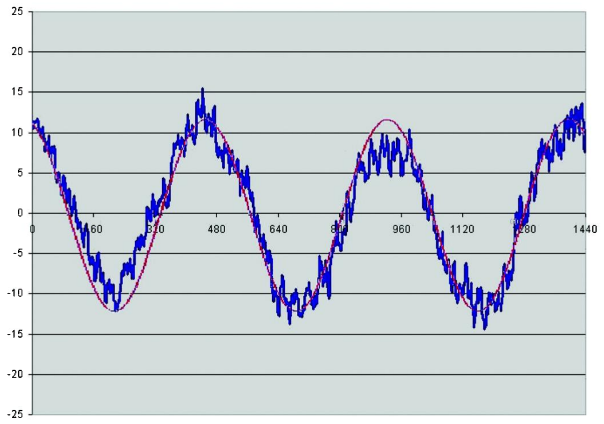

Figure 5 — Example of a large but relatively smooth periodic error.

The PE curve displayed in Figure 6 shows just how bad a modern mount can be. This is also from a popular mount that is touted by the manufacturer as being well-suited for imaging. I have tried to fit a sine curve over this mount's PE curve, but it was not as simple a task as in the previous example. This mount would not be very useful for imaging without some work.

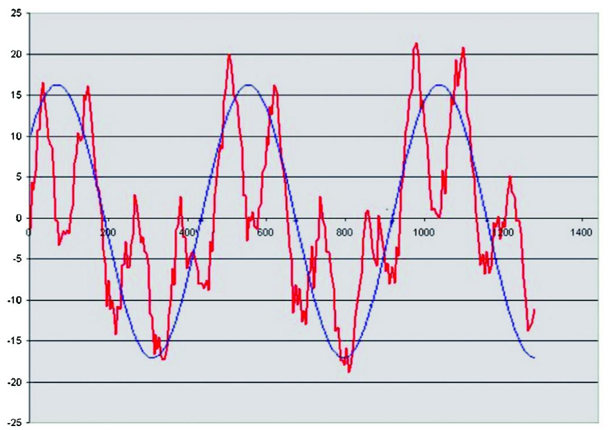

Figure 6 — Example of a large and very erratic periodic error.

Today, just about everyone is guiding their images, so normally any PE will be guided out. The amplitude of the PE curve isn't generally an issue, but the shape of the curve is critical. Figure 6 shows many areas where the curve is so steep that an auto-guider may not be able to correct for the changes quickly enough.

Even if it displays a bad PE curve like Figure 6, a mount may still be usable for imaging. Most mounts these days come with some form of periodic error correction (PEC) built into their firmware. PEC has always been a rather dark art to me, and I never really did get it to work properly on my HEQ5. I don't even try on my CGE, as it isn't needed. The theory of how PEC works is quite simple. Start the mount's PEC "learn" routine and let the mount run over three or four worm revolutions (see calculation below) while guiding on a star. While in learning mode, the PEC system records all guiding done by you or an autoguider. Once stored, the PEC system reverts to "playback," repeating any guiding corrections that were recorded during the training session, speeding up and slowing down as needed to smooth out the curve.

There may be a problem using PEC while auto-guiding in that the guider, during its calibration phase, is doing its calculations with no knowledge of any worm rotation speed changes. If the mount is being guided during times of very slow or very fast worm rotation, as dictated by the PEC routines, then guider error could be introduced. This may or may not be an issue, but SBIG has in the past stated that PEC should be turned off when using their guiders.

So how good is PEC? Generally quite good from the examples I've seen, where people have taken their time and used the available software tools correctly. With very good mounts, PEC can reduce error to the point where an auto guider isn't needed for short(ish) exposures, making the system good for survey or patrol duties. Generally it's not good enough for long-exposure imaging with mounts that normal humans can afford.

There are several software tools available to help with determining the amount of PE a mount exhibits and to smooth out the PEC routines. If the plan is to use both PEC and an auto guider, it would be in your best interest to check the on-line forums to see if there will be any issues.

Figure 7 shows a Fourier analysis of the Figure 5 curve. A Fourier analysis is used to break apart the periodic wiggles in the tracking and turn them into a myriad of sine curves that, when added up, reproduce the curve being analyzed. Each sine curve in the Fourier analysis represents a frequency; some are very quick corrections, others are slower, and still others are quite leisurely. The various frequencies can be plotted on a graph (the frequency of the frequencies), where the most common corrections show up as "spikes" or high spots in the chart, as in Figure 7. The centre of a spike represents the period of that curve. This type of chart shows the PE generated by all of the gears between the motor and the worm-gear individually. As can be seen in the graph, the analysis of the Figure 5 curve shows really only two periods:

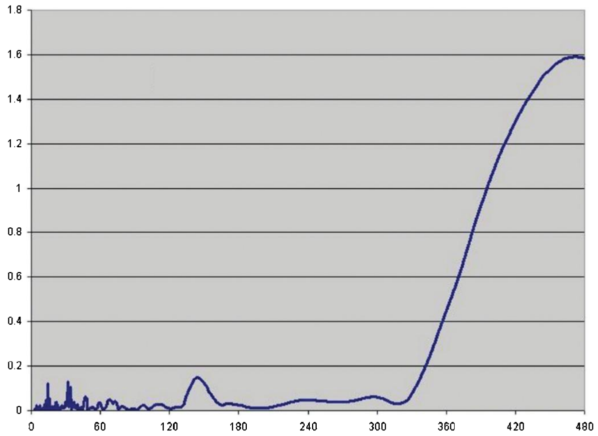

Figure 7 — Fourier curve showing the relative frequency of the periods of guiding errors in the gear of Figure 5.

a large hill on the right side with a period that peaks near 480 seconds and a smaller hump at about 150 seconds that is probably due to some error in the transfer gears between the motor and worm.

Figure 8 shows a typical worm-gear setup. Places where periodic errors are generated are in the worm and gear, the transfer gears, and in the gearbox of the motor. Errors generated in the gearbox usually show up as the "noise" at the far left of the Fourier analysis graph. Unless they are very bad, the PE from the gearbox and transfer gears normally does not have a deleterious effect on tracking. Fixing transfer gear PE could be difficult. Dirty or sticky bearings in the worm's shaft may also add to the noise in the Fourier analysis.

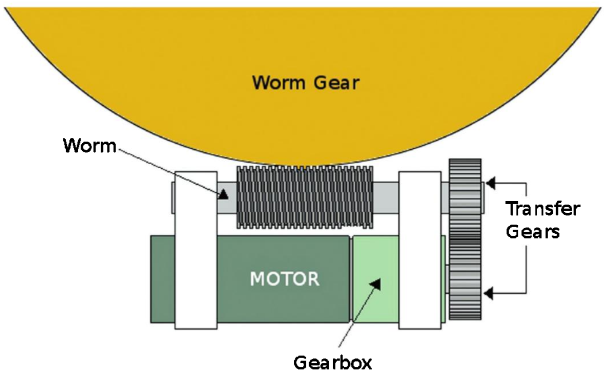

Figure 8 — A schematic of a standard worm-gear setup.

A low periodic-error value in the specifications of a mounting may be an indication of the quality of the gears used in its manufacture. A mount maker with some integrity would state the maximum allowable PE that one of their mounts displays before the gears are rejected, but not all manufacturers are that forthcoming; at best, you can expect to see the average PE. It should also be kept in mind that different samples of similar mounts from a single manufacturer may show differing PE, though all will be within the acceptable range of the maker's quality-assurance specifications. ✶

Rick Saunders became interested in astronomy after his father brought home a 50-mm refractor and showed him Saturn's rings. Previously a member of both Toronto and Edmonton Centres, he now belongs to the London Centre, and is mostly interested in DSLR astrophotography.

Calculating worm period

A PE curve will have an amplitude equal to the greatest excursion of the star from centre, and a period that can be calculated using the following relationship:

Period = 86164 / number of teeth in the worm gear

So, a gear with 180 teeth will have a worm period of 479 seconds, while a gear with 360 teeth will have a period of 239 seconds. A telescope mount's documentation will generally tell how many teeth are on the worm gear and (possibly) the average periodic error that the manufacturer specifies for the mount.