Motorization of an EQ3 mount

The original EQ3 mount (before modifications)
THE ORIGINAL MOUNT

The photos on the previous page show the EQ3 mount as it was before the modifications.

This German equatorial mount was equipped with a single stepper motor in right ascension which could track at sidereal speed to keep the targeted object stationary in the field of vision. The original control box also made it possible to make minor movements up to 8X sidereal speed using buttons.

As there was no declining motor, the movements of this axis were done manually using a wheel at the end of a flexible rod.

With this mount, tracking made it possible to make visual observations with a small telescope and take pictures of the sky with exposures up to 60 seconds if the mount was perfectly aligned and if the focal length was short: camera equipped with a telephoto lens for example.

It was not possible to automatically guide with a guide camera to be able to use longer exposures and longer focal lengths.

THE MODIFICATIONS

The goal of the project is precisely to correct this problem by adding a declination motor and a control box which allows to make autoguiding and several other functions.

CALCULATIONS FOR THE MODIFICATIONS

Each axis of this mount is driven by a worm gear.

The right ascension gear has 120 teeth and therefore it takes 120 turns of the worm to make 360°. The declination gear has only 66 teeth.

With a pitch of 48 teeth per inch in diameter, the right ascension gear is 2.5 inches in diameter and the declination gear is only 1.375 inches in diameter.

Despite the small dimensions of the gears, we want to obtain photos of the deep sky without star trails up to a focal length of at least 600mm, with for example an 80ED refractor at F / 7.5. It will be a challenge. This will allow us to have a small, very portable mount to bring to sites where there is no light pollution.

The following pages show the calculations made with the SKYPIKIT MOTOR TESTER TUNER application to find out the characteristics of the drive and to choose the right motor and gears to add to the declination axis.

The original right ascension stepper motor is retained. The motor added in declination is a DC motor with Polulu encoder.
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New declination system including the DC motor with encoder and the gears.

In right ascension, we keep the original stepper motor of the EQ3.

The simple handbox and the control box including the Arduino and the PLEIADES-2 set of circuits.
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Assembly of mechanical parts in declination
Motorization of an EQ3 mount

The control box and its functions
Motorization of an EQ3 mount

Interior view of control box

R.A.  Decl.  Arduino
Motorization of an EQ3 mount

This mount used the circuits of the PLEIADES-2 set of boards
CALCULATIONS FOR MODIFICATIONS IN RIGHT ASCENSION

*The data are as follows:*

The main gear on the right ascension axis has 120 teeth.

Each turn of the worm advances one tooth.

The motor reduction box reduces the speed by 31.36 X (calculated by trial and error by carrying out tests).

The reduction of the other gears of the system is 1 X since the output of the reduction box of the motor is directly coupled to the axis of the worm.

The number of steps per revolution of the motor rotor is 200 (calculated by trial and error by carrying out tests).

We choose 16 micro-steps per step to control this stepper motor, which will give 16 X 200 = 3200 micro-steps per revolution of the motor rotor.

By tests, we find that this stepper motor can rotate reliably up to the speed of 14000 micro-steps per second before going wrong (with the circuits used).

*The results obtained are as follows:*

See next page.

3200 micro-steps are required for one revolution of the motor rotor.

The sidereal tracking speed corresponds to 139.7594 micro-steps per second.

A micro-step corresponds to 0.107 arcsec, but the realistic resolution is rather 0.429 arcsec.

The maximum reliable speed of movement (SLEW or GOTO) of 14000 micro-steps per second corresponds to a speed of 0.4185 degrees per second for the telescope.

For a movement speed of 1 degree per second, the motor would have to accept 33450.6667 micro-steps per second, which is far above its capacity.

We finally choose a maximum movement speed (SLEW or GOTO) of 0.400 degrees per second, just a little below the reliable maximum (0.4185).
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### SETTINGs

<table>
<thead>
<tr>
<th>Number of Teeth of the Main Worm Gear</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Worm Gear Teeth Advance / Revolution of the Main Worm</td>
<td>1</td>
</tr>
<tr>
<td>Reduction of the Motor Reducer</td>
<td>31.36</td>
</tr>
<tr>
<td>Reduction of the Other Gears in the System</td>
<td>1</td>
</tr>
<tr>
<td>Nominal Number of Full Steps / Revolution or the Motor Rotor</td>
<td>200</td>
</tr>
<tr>
<td>Number of Microsteps / Full Steps</td>
<td>16</td>
</tr>
<tr>
<td>Reliable Tested Maximum Speed in Microsteps / Sec.</td>
<td>14000</td>
</tr>
</tbody>
</table>

### RESULTS

This motor outputs 3200 microsteps / revolution of the motor rotor.

Calculated sidereal tracking speed with given data = 139,7594 microsteps/sec.

One microstep count = 0.107 arcsec

Realistic motor resolution = 0.429 arcsec

Maximum slew or goto speed = 14000 microsteps/sec or 0.4185 degree/sec

Slew speed for 1 degree/sec = 33450.6667 microsteps/sec

Calculations for modifications in right ascension
CALCULATIONS FOR MODIFICATIONS IN DECLINATION

The data are as follows:

The main gear on the declination axis has 66 teeth.

Each turn of the worm advances one tooth.

The Polulu motor reduction box reduces the speed by 131.25 X (precise value supplied by the motor manufacturer).

The reduction of the other gears of the system is 4.2 X since we chose a pinion of 20 teeth on the axis of the reduction box of the motor and a gear of 84 teeth on the axis of the worm (84/20 = 4.2).

The number of steps per revolution of the motor rotor is 64 (quadrature encoder at 64 steps / revolution).

At 12 volts, the nominal speed of the DC motor chosen at the output of its reduction box is 80 RPM (80 revolutions per minute).

The results obtained are as follows:

See next page.

With a nominal voltage of 12 volts, the rotor of the chosen DC motor rotates at a speed of 10500 RPM, or 175 revolutions per second.

With this voltage of 12 volts and this speed of 175 revolutions per second, the quadrature encoder emits a signal at a speed of 11200 steps per second.

The sidereal tracking speed corresponds to 27.0238 steps of encoder per second.

One encoder step corresponds to a resolution of 0.555 arcsec.

The maximum suggested speed of movement (SLEW or GOTO) of 8960 steps of encoder per second corresponds to a speed of 1.385 degrees per second for the telescope.

For a slew speed of 1 degree per second, the motor would have to run at 6468 steps of encoder per second, which it is easily able to do.

We finally choose a maximum speed of movement (SLEW or GOTO) of 0.800 degrees per second. We could go faster but this speed is already twice that of right ascension (0.4 ° / s). This choice also reduces engine noise and can reduce wear.
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### Calculations for modifications in declination

<table>
<thead>
<tr>
<th>SETTINGS</th>
<th>CONTROL</th>
<th>ANALYZE</th>
<th>DC motor calculation</th>
<th>STEPPER motor calculation</th>
<th>FOCUSER calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>66</td>
<td></td>
<td></td>
<td>number of teeth of the main worm gear</td>
<td>1</td>
<td>main worm gear teeth advance / revolution of the main worm</td>
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<tr>
<td>131.25</td>
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<td></td>
<td>reduction of the motor reductor</td>
<td>4.2</td>
<td>reduction of the other gears in the system</td>
</tr>
<tr>
<td>64</td>
<td></td>
<td></td>
<td>quadrature encoder counts / quadrature encoder revolution</td>
<td>80</td>
<td>nominal RPM at the output of the motor reductor at nominal voltage</td>
</tr>
</tbody>
</table>

**RESULTS**

- Full speed of the motor rotor at nominal voltage = 10500 RPM or 175 revolutions/sec.
- Full quadrature encoder speed at nominal voltage = 11200 counts/sec.
- Calculated sidereal tracking speed with given data = 27,0238 counts/sec.
- One quadrature encoder count = 0.555 arcsec
- Suggested maximum slew or goto speed = 8960 counts/sec or 1,385 degree/sec
- Slew speed for 1 degree/sec = 6468 counts/sec
Right ascension control parameters

The motor type is "Stepper" since it is the original stepper motor of the EQ3.

The address of the right ascension controller is 65 and this controller operates in the sidereal reference system.

The sidereal speed of 139.76 micro-steps / second is that calculated with the SKYPIKIT MOTOR TESTER TUNER application and explained earlier in this document.

This last application was also used to calculate the maximum GoTo speed of 13,380 micro-steps / second which corresponds to 0.4 degrees / second.

Since acceleration has the same value as Goto's speed, it means that it takes a second to reach maximum speed in GoTo.

The negative final approach means that it is in the same direction as the tracking, towards the West.

PI control parameters are not used with a stepper motor.
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Adjustment of control parameters (declination)

Control parameters in declination

The motor type is "DC servo" since it is the added DC Polulu motor with quadrature encoder.

The address of the right ascension controller is 66 and this controller operates in the fixed reference system.

The sidereal speed of 27.024 steps / second is that calculated with the SKYPIKIT MOTOR TESTER TUNER application and explained earlier in this document.

This last application was also used to calculate the maximum GoTo speed of 5174 steps / second which corresponds to 0.8 degrees / second.

Since acceleration has the same value as Goto's speed, it means that it takes a second to reach maximum speed in GoTo.

The positive final approach means that it is always towards north.

The PI (proportional-integral) control parameters were determined with the SKYPIKIT MOTOR TESTER TUNER application. See the document on this application.

Configuration page for declination parameters in the "SKYPIKIT FEX program."
Finally, here is the EQ3 mount, complete with its new control box, its new handbox, its original right ascension stepper motor and its added declination servo DC motor.

The tests were carried out with a StarShoot Autoguider guide camera at the focal point of a SkyWatcher 80ED telescope with a focal length of 600mm.

At this scale, a 5.2 µm guide camera pixel is equivalent to 1.79 arc seconds.

A star of magnitude 6 was used as the guide star.
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These tests give some of the best results obtained with the PHD2 Guiding autoguiding software for a period of approximately 2 minutes. The curves show the measured positions and the bars show the autoguiding corrections of the Orion StarShoot Autoguider guide camera in On-camera mode.

The total RMS of 1.16 " means that the star is theoretically inside a circle of 1.16 arc seconds for 68% of the measurements and that it is inside a circle of 2.32 seconds of radius arc for 95% of the measurements.

With several measurement sequences, the total RMS results were variable. The best was 0.9 "and the worst 2.5". Autoguiding corrections are difficult in declination because of the small radius of the gear (worm gear), only 11/16 of an inch (17.5mm). Be careful to balance the telescope well and tighten the worm bolts properly, enough but not too much.

The green square added to the target represents one pixel on a computer screen when a photo taken with a digital camera at the focal point of a 600mm focal length telescope is displayed at 1600 pixels wide on the screen. One pixel of screen is equivalent to 4.5 seconds of arc. In the example shown, we can see that almost all the points measured in this sequence are within a single screen pixel.
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A test image: the double cluster of Perseus

Double cluster of Perseus, by Pedro Borquez, ED telescope 80 mm aperture, 600 mm focal length, Canon camera, 9 exposures of 240 seconds combined with the Deep Sky Stacker application.