

The EQMOD Project

PECPrep

Periodic Error Analysis and Correction file generator

User Guide

Contents

Introduction	3
Menu Items.....	5
Mount	5
File.....	5
Periodic Error Analysis Tab.....	7
Main Graph.....	7
Stacked Cycle Graph.....	7
Statistics.....	8
FFT Smoothing.....	8
Filter Controls.....	9
Periodic Error Correction Tab.....	11
Periodic Error Curve.....	11
Cycle Weightings.....	11
Periodic Error Correction Curve.....	11
Residual Error.....	11
PEC Curve Arithmetic Tab.....	12
Frequency Spectrum Tab.....	13
Spectrum Graph.....	13
Graph Options.....	13
Magnitude Threshold.....	13
Graph Type.....	14
FFT Controls.....	14
Window.....	14
Running Average.....	15
Resolution.....	15
Reference Spectrum.....	15
Significant Mount Periods.....	15
Data View.....	15
EQMOD PEC Generation - worked example:.....	17
Periodic Error Simulations.....	21
APPENDIX A: RA Axis Rotational Periods.....	22
APPENDIX B: Capturing PE Data.....	24
Choice of Equipment.....	24
Choice of Capture Program.....	24
Star Selection.....	24
APPENDIX C: Analysing PE Data.....	25

Introduction

PECPrep is a free, open source application for the analysis of your mounts Periodic Error (PE). It can import data from variety of different capture sources. PECPrep is able to filter wind, seeing effects, linear and non-linear drift to isolate the periodic signal associated with a mounts worm drive. In addition to Periodic Error analysis, PECPrep can also be used to generate a Periodic Error Correction (PEC) file for use by the EQASCOM driver for EQ type mounts.

PECPrep can analyse PE data captured by several popular capture and guiding applications:

- [perecorder](#) (Specially written for close integration with EQASCOM)
- Stark Labs PHD
- K3CCDTools
- MaxImDI
- Guidemaster
- Metaguide
- CCDTools
- AstroArt

PECPrep uses Fourier analysis to build a best fit model of the PE curve. By using Fourier Transforms the PE signal is modelled as the combination of a series of sine waves of differing amplitude, frequency and phase. In this way it is possible to identify and filter frequency components from the original data and this can be used to identify and isolate potential mechanical problems such as excessive play in transfer gears etc. This technique of using Fourier Analysis is a well established method widely applied in industry for vibration and failure analysis of motors/and and associated gear trains.

The PECPrep user interface has been carefully designed to provide the user with clear visual cues whilst data is processed in both the time and frequency domains.

- Linear regression to remove linear drift (tracking error)
- Non linear drift effects such as those induced by low frequency oscillations can be removed using a High Pass filter
- High frequency noise (such as introduced by seeing fluctuations) can be removed using a Low Pass filter
- Individual frequency components can be removed
- Individual frequency components can be isolated to assess their contribution to Periodic Error.
- Auto filter provides a quick intelligent filter selection.

PECPrep provides detailed analysis of the Frequency Spectrum and data can be compared against a previously saved reference, perhaps to evaluate the effectiveness of mechanical adjustments such as bearing replacement/lubrication etc.

- Different windowing options available for better extraction of frequency/magnitude.
- Variable frequency resolution allows the tuning of analysis to a particular region of the spectrum.
- User definable "significant periods" for quick analysis of common mount characteristics.

Once the periodic error signal has been filtered and smoothed the resulting cycles can be combined to build a Correction Curve for use by EQASCOM.

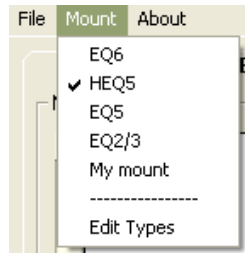
- Individual cycles can be removed
- Weighing factors allows control over relative influence of each cycle
- The residual error display allows the user to determine the best fit Correction Curve.

PEC curves can be further or manipulated via the PEC Curve Arithmetic tab:

- Curves can be refined by subtracting error data from a second recording.
- Automatic synchronisation of data with respect to stepper motor position.
- Phase to compensate for system delays.
- Resynchronisation of correction phase via manual alignment.

Menu Items

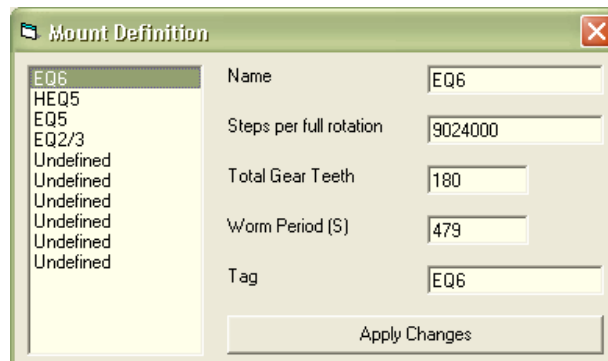
Mount



Make sure to set your mount type.

To edit or add mount definitions select Edit Types

Select an entry from the list, make changes and then hit "Apply" changes. Setting the Name to nothing sets the type as undefined. Undefined types will no be listed under the Mount menu.



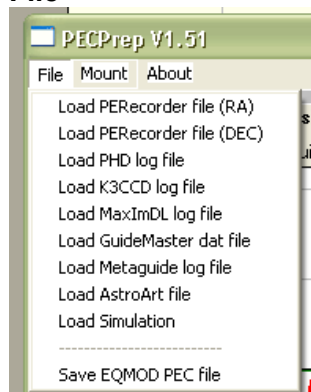
"Steps per full rotation" is used as part of the EQMOD VS-PEC generation. If you don't intend using this function then just set this value to any non-zero value.

"Total Gear Teeth" refers to the RA worm gear and used as part of the EQMOD VS-PEC generation. If you don't intend using this function then just set this value to any non-zero value.

Worm Period is used to set graphing grid lines and determines how the data is processed to produce a stacked cycle display.

The "Tag" entry is used to locate frequency spectrum data within the marks.def file (see frequency Spectrum Tab documentation below)

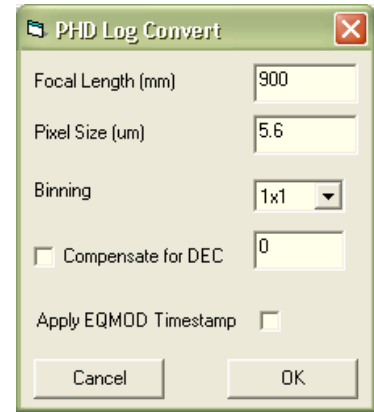
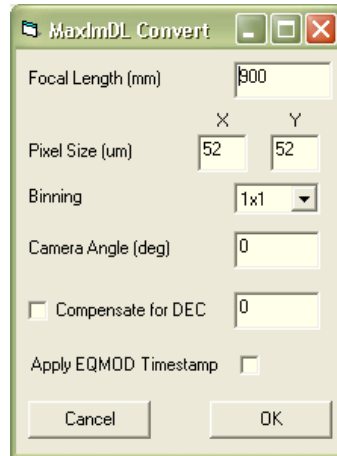
File



PECPrep loads the following types of files:

- peregorder files (raw or smoothed)
- PHD log files
- K3CCDTools drift logs
- MaximDI track logs
- GuideMaster Logs
- MetaGuide Logs
- AstroArt files
- CCDSoft files
- PECPrep simulation definitions

Each file type brings up its own associated dialog.



If you just want to analyse your Periodic Error there is no need to apply the EQMOD Time Stamp – **This is only needed when preparing PEC files for use by the EQASCOM driver.**

Periodic Error Analysis Tab



Main Graph

The top left graph shows your mounts PE, the top right graph is the same data but with worm cycle overlaid on top of each other so direct comparisons can be made.

Raw data = Unprocessed data

Raw-Trend = Raw data with linear regression applied

Smoothed = Raw-Trend with FFT Smoothing applied

Noise = Raw-Smoothed

Linear Regression:

Use this to remove any inherent RA drift from the Raw data. If loading just a single cycle of data it is probably best to not apply regression.

Stacked Cycle Graph

The stacked cycle graph reproduces the smoothed data curve but with all cycles plotted against the same time frame. In this way you can easily identify any significant differences in shape or phase. Below the graph are a slider and dropdown list that set the period of the PEC curve to be produced. By default this will be set to the mounts worm period however you can change this if you want to isolate other periodic signals.

Statistics

The Statistics are calculated using the smoothed data curve. If you want statistics for the raw curve then simply remove any filters such that the smoothed data follows the raw data. Using the smoothed data curve allows you to use the filters to remove wind and seeing disturbances that might otherwise affect the figures.

Max Delta = maximum change between successive samples of raw data.

You can select and copy the various stats marking and right clicking.

If linear regression is applied the trend will show you how much linear drift was occurring. So if the display shows

$$Y=0.0142x + 5.9$$

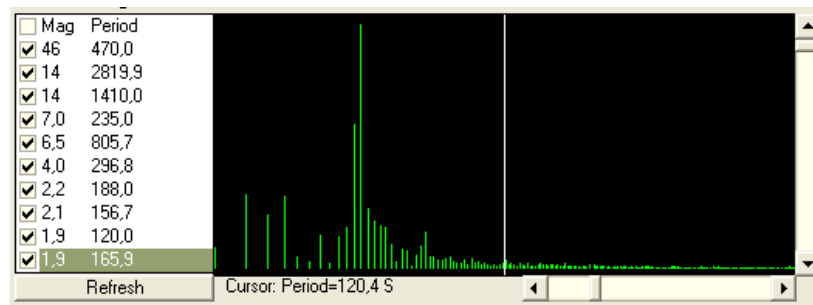
... this means the mount is drifting in RA at a rate of 0.0142 arcsecs/sec

FFT Smoothing

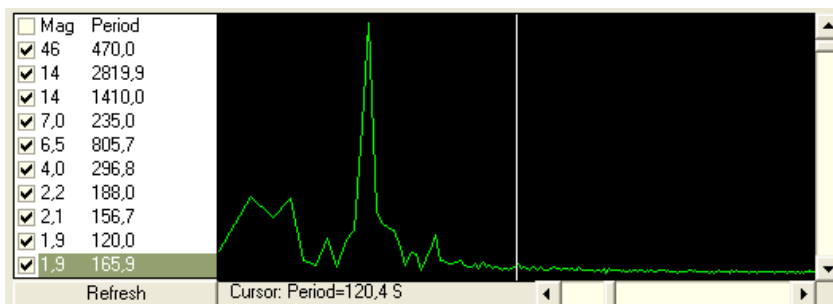
Frequency analysis and filtering is achieved using a Fast Fourier Transform (FFT). The principal behind FFT is that any waveform can be constructed by combining multiple sine waves of different amplitude, phase and frequency. Using Fast Fourier Transforms is well established technique within the field of controls, communications and image processing and identifies key frequencies present in sampled data allowing selective filtering to be applied (for instance to remove fixed pattern noise from an image).

By applying Fourier transforms to our mount's PE signal we can identify mechanical components that are contributing to the PE. By the use of selective filters we can then remove unwanted frequencies from our data such as those caused by seeing, wind or flexure.

The Frequency Analysis display shows a series of peaks, each representing a frequency present in the PE signal. The larger the peak, the more significant the contribution to the PE. The 10 most prominent peaks listed present within the unfiltered area of the spectrum are listed. Use this as a **guide only** so the 470 second peak listed will actually correspond to the 479s worm period.



The white Cursor can be moved by clicking/dragging on the graph area. The graph area can be 'zoomed' via the sliders. Right Clicking on the frequency graph switches the display between discrete to continuous mode.



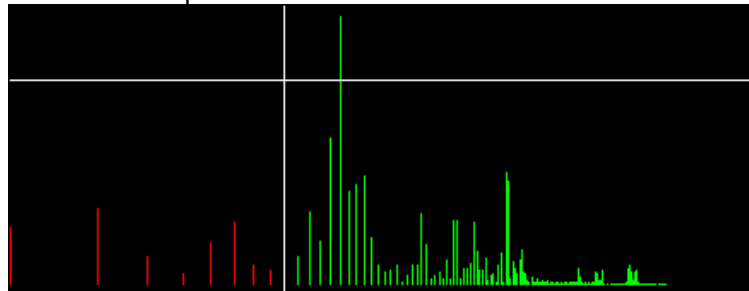
Filter Controls

The filter controls permit a great deal of flexibility over how the raw data is filtered and smoothed.

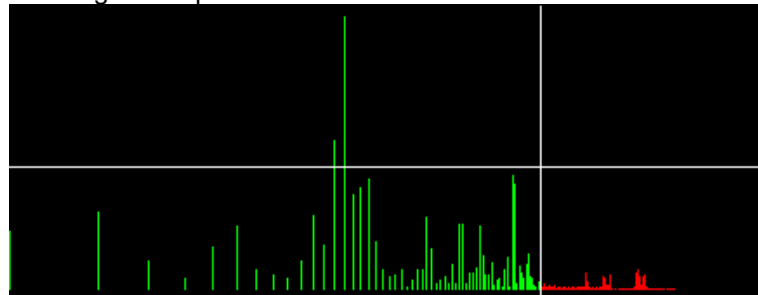
When filters are changed the PE, Stacked PE, Statistics and Frequency Spectrum displays will all be updated. Choosing the best filter levels may require you to watch the effects in all displays. Where a filter applies to the data it is drawn in red, unfiltered data appears green.

Each filter has an associated “set” and “reset” button. To set a filter, just move the white cursor to the desired point on the spectrum and hit the “set” button. To remove a filter, use the “reset” button.

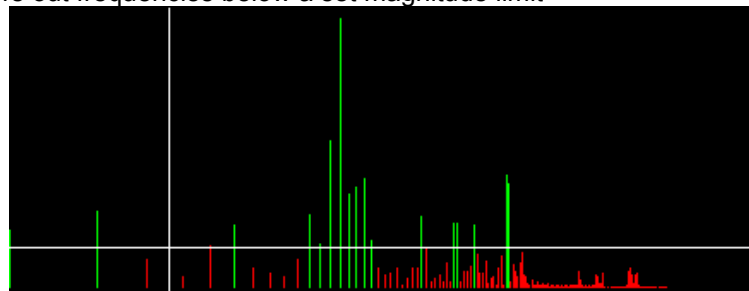
The HighPass filter filters out lower frequencies



The LowPass filter filters out higher frequencies

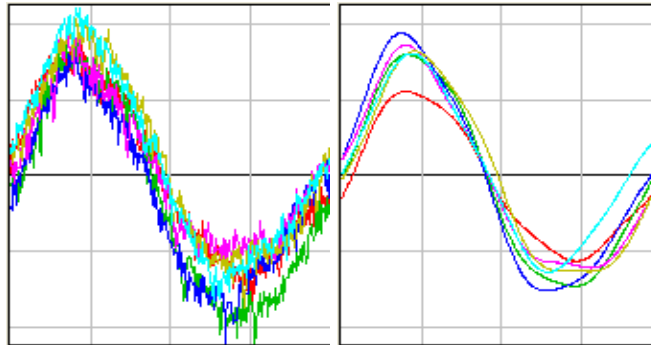


The MagLimit Filter filters out frequencies below a set magnitude limit

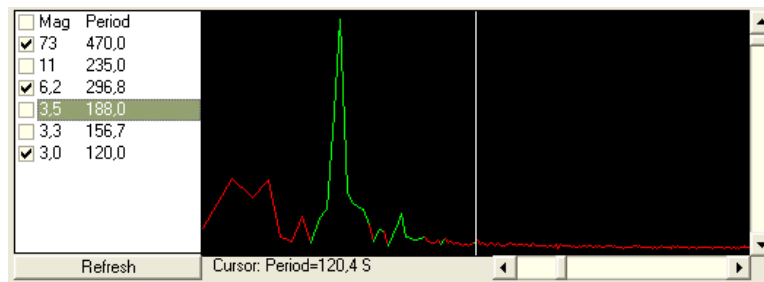


The AutoFilter button will apply a MagLimit filter to remove frequency components with magnitudes low than the 10th most significant and a high pass filter that removes any frequency components lower than that of the worm period.

Notice how the Stacked PE graph changes as the filters are applied. Below is a comparison between unfiltered and Auto Filtered



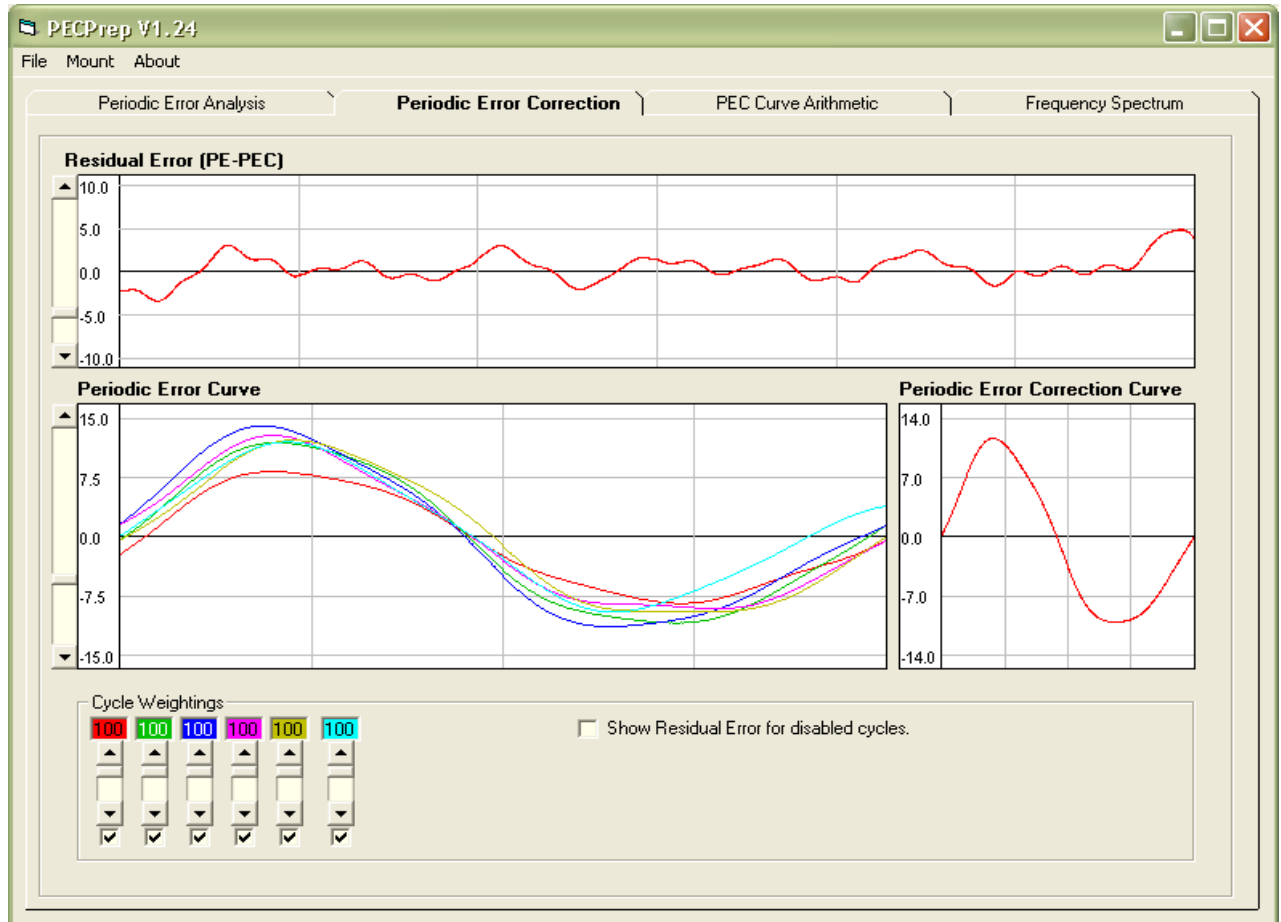
Individual frequencies can be removed from the filtered response by using the check boxes.



This is particularly useful in assessing the contribution of each component and also allows removal signals that are not harmonic with the fundamental worm period.

Periodic Error Correction Tab

The PEC tab is where the smoothed PE data produced on the PE tab is processed to create a PEC curve for use by EQASOM. Although the PEC generation is specific to EQASCOM the graphs shown on this tab may still be of use to owners of any mount and can give you an idea of the level of PEC performance that might be achieved.



Periodic Error Curve

The Smoothed PE curve is displayed as overlaid cycles. This lets you see how one cycle compares with the next and to easily identify 'bad' data.

Cycle Weightings

Each cycle can be given a weighting as to its contribution to the final PEC curve. Rouge cycles can be removed all together via the associated check boxes.

Periodic Error Correction Curve

The PEC curve is the result of the weighted average of all the individual PE cycle (excluding any that have been disabled). This average curve is adjusted to remove any linear drift over the period.

Residual Error

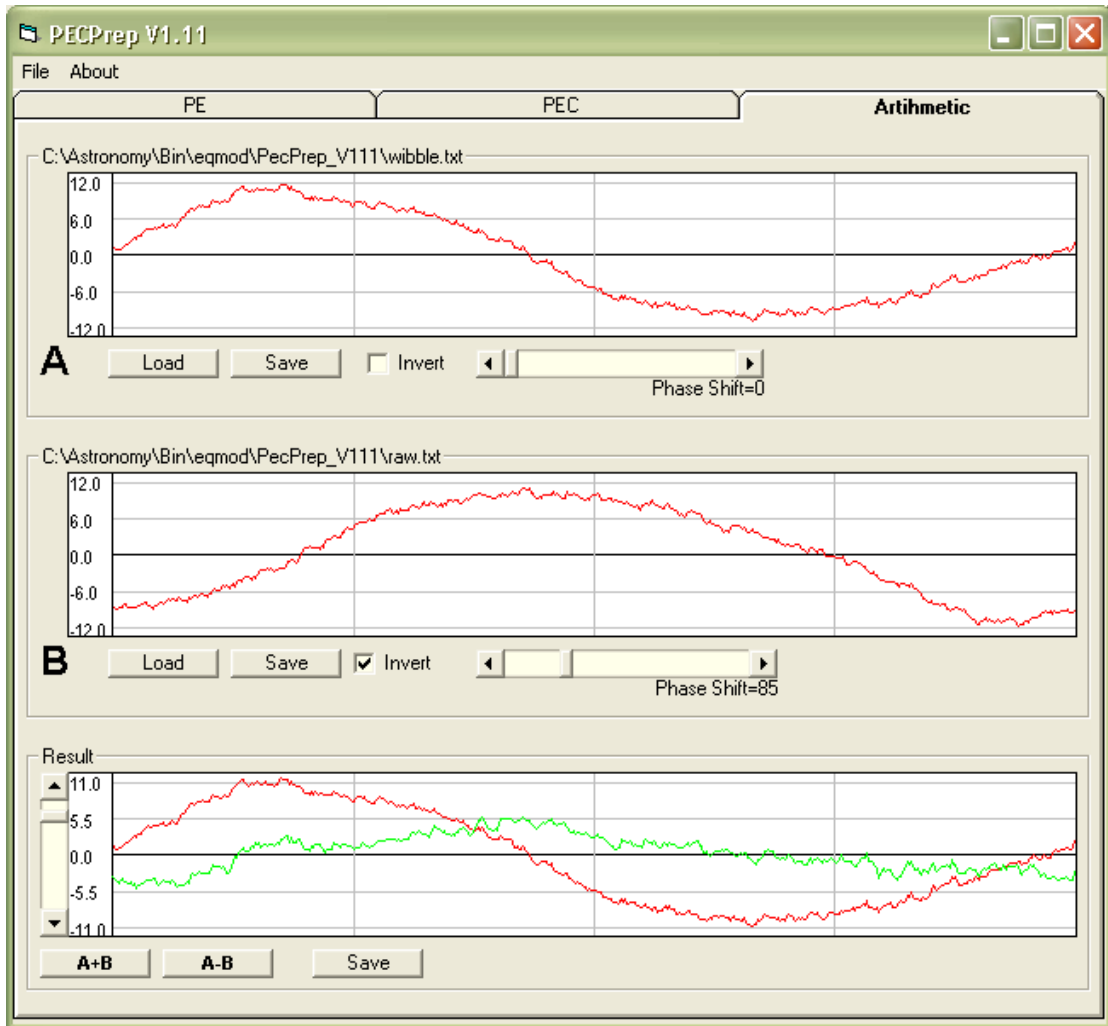
The Residual Error trace shows what is the theoretical result if the Periodic Correction Curve had been applied to the smoothed data.

$$\text{Residual Error} = \text{Smoothed PE curve} - \text{PEC curve}$$

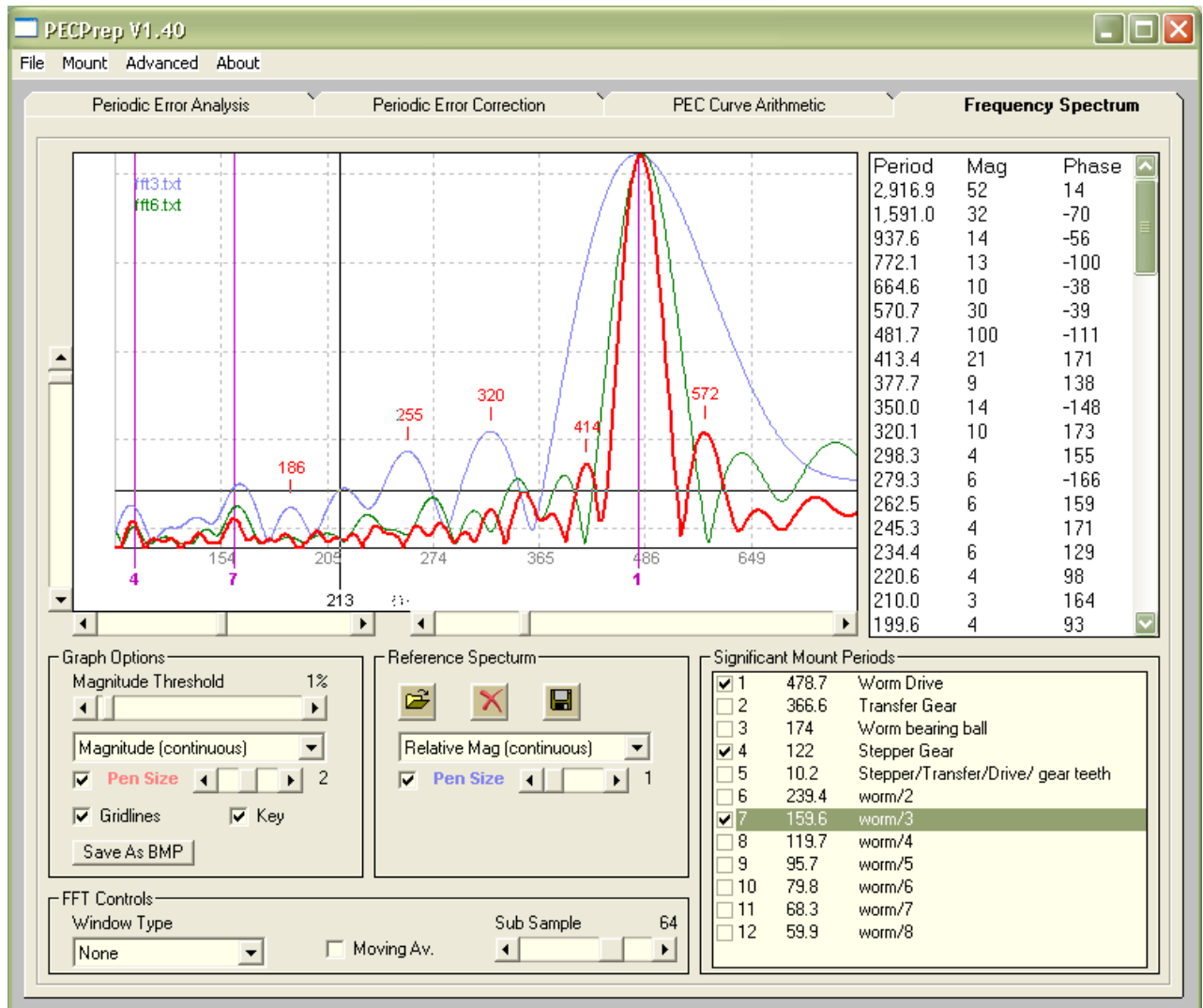
You may find that by adjusting the cycle weightings you can produce a flatter residual error.

PEC Curve Arithmetic Tab

The Arithmetic Tab allows PEC curves to be added, subtracted, inverted and phase shifted.



Frequency Spectrum Tab



The Frequency Spectrum tab provides detailed analysis of the currently loaded PE data and allows direct comparison with other previously saved reference data.

Spectrum Graph

The red trace represents the currently loaded PE loaded data. Up to 5 reference traces can be loaded, each being displayed in a unique colour – an optional graph key can be displayed to identify the reference curves.

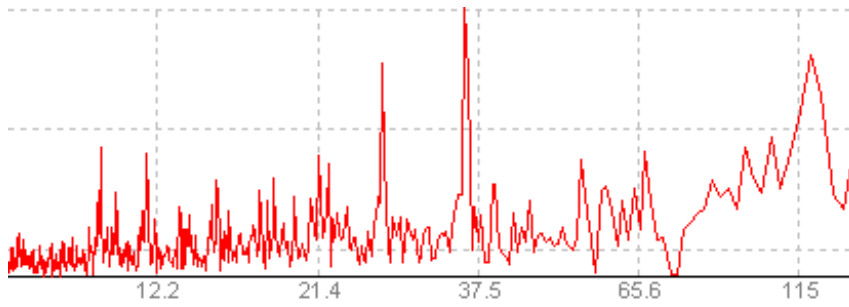
Left click to move cursor, right click to plant label. Y axis units are relative magnitude so the represent % of the highest magnitude present. Left clicking and move off window will scroll/zoom the window.

The sliders attached to the graph provide the ability to zoom and shift the graph area.

Graph Options

Magnitude Threshold

The “Magnitude Threshold” slider allows you to set the minimum magnitude of signal that is plotted. This is useful for removing the low level noise form the spectrum display and for removing insignificant peaks from the data list to the right of the graph.



If the Magnitude Threshold is increased – only the more significant peaks are displayed.

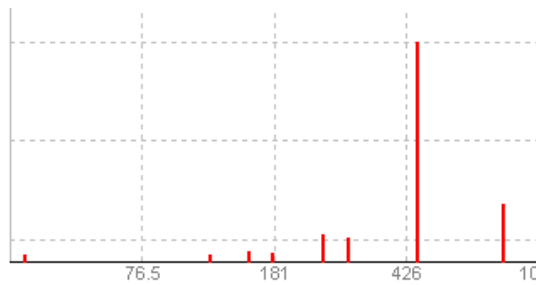


Graph Type

The spectrum plot can be selected to be either continuous.....



....or to just show the peaks



FFT Controls

Window

Windows reduce bleeding between signals in the frequency domain and then different types can provide better isolation of frequencies. Hamming, Hanning, Blackman, FlatTop and Rectangular (None) window options are provided by the drop down.

Window Type	Frequency Resolution	Spectral Leakage	Amplitude Accuracy
None	★★★★	★	★
Blackman	★	★★★★★	★★★
FlatTop	★	★★★	★★★★★
Hanning	★★★	★★★	★★
Hamming	★★★	★★	★★

Running Average

A running average can be applied to the power spectrum to remove ‘noise’ and better identify the significant peaks. Also the magnitude threshold slider can be adjusted so that only those peaks above a significant magnitude are graphed.

Resolution

Discrete FFTs work by using “Bins” that quantize the frequency domain. The “Resolution” slider can be used to control the FFT sampling rate of the raw data. Sampling the data at a lower rate reduces the “Bin Width” and there for delivers greater resolution of frequencies/periods at the expense of losing range at the high frequency (short period) end of the graph. The slide sets the minimum period that can be show. So setting the slider to 30S gives you the greatest resolution but you will lose any data that has a period of 30S or less.

Reference Spectrum

Saving the current data as a reference allows you to compare future results with the current one - data is exported to a “space delimited “ file which you can also load into a spreadsheet for further analysis.

Significant Mount Periods

The list of Significant Mount Periods is read from the marks.def file (a text file you can edit using notepad). The Tag that forms part of the mount definition is used to locate which data from the marks.def file is loaded. In this way several mount types can share common data. Appendix A lists the rotational periods of some RA Axis components for EQ6 Pro and HEQ5 mounts

Data View

The list to the right of the graph area gives the details of all the peaks present in the graph taking into account the magnitude threshold setting. The phase of each peak is listed and this can be useful for identifying elements that originate from the same mechanical source. By clicking on an entry you can force that particular phase to appear as 0 and all other phases adjusted according. This is useful for assessing the phase difference between signals or for setting a standard reference point when comparing responses.

Period	Mag	Phase
2,916.9	52	14
1,591.0	32	-70
937.6	14	-56
772.1	13	-100
664.6	10	-38
570.7	30	-39
481.7	100	-111
413.4	21	171
377.7	9	138
350.0	14	-148
320.1	10	173
298.3	4	155
279.3	6	-166
262.5	6	159
245.3	4	171
234.4	6	129
220.6	4	98
210.0	3	164
199.6	4	93

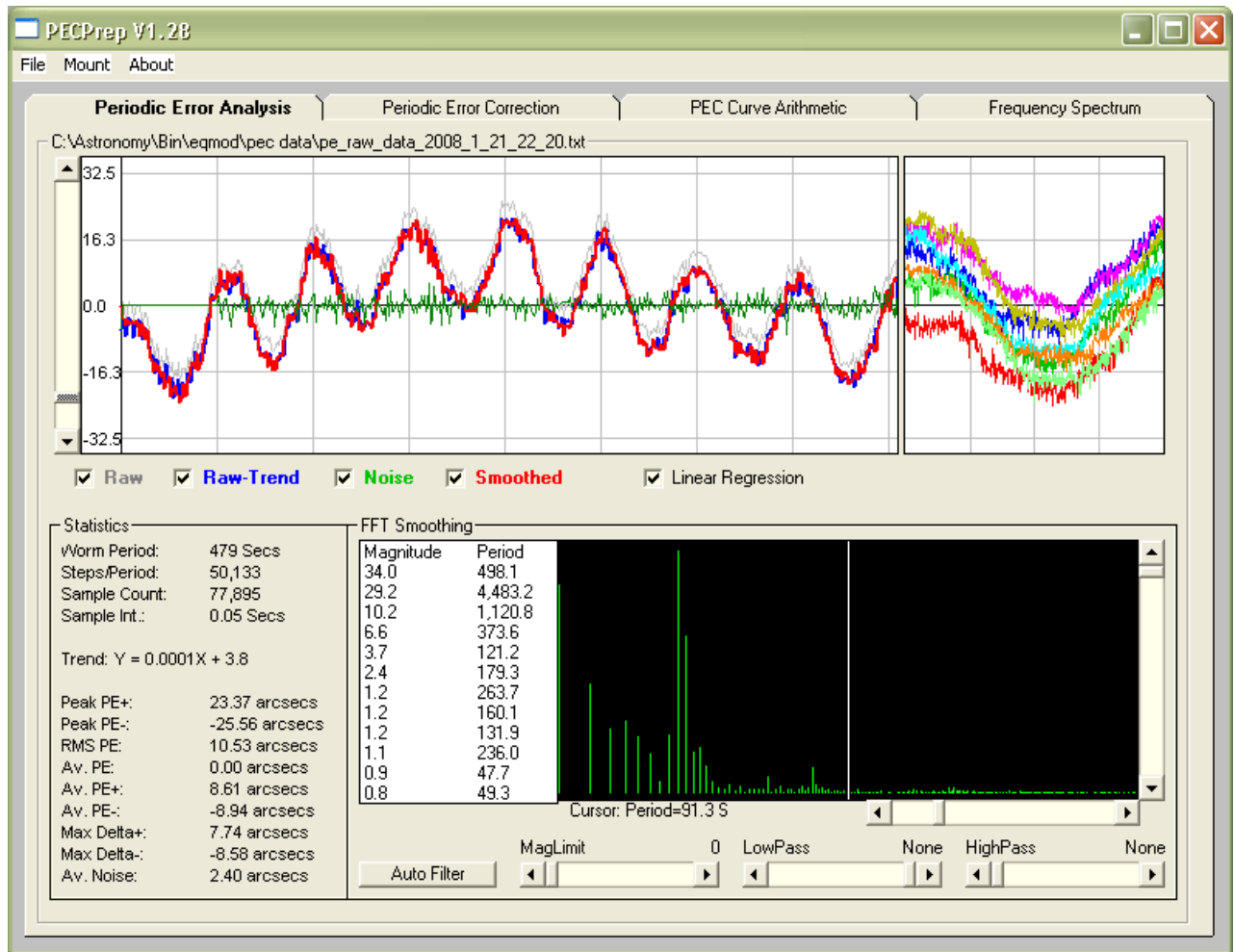
Clicking on the entry of period 481.7 sets its phase to 0 and recalculates all other phase values relative to that point.

Period	Mag	Phase
2,916.9	52	125
1,591.0	32	41
937.6	14	55
772.1	13	11
664.6	10	73
570.7	30	72
481.7	100	0
413.4	21	-78
377.7	9	-111
350.0	14	-37
320.1	10	-76
298.3	4	-94
279.3	6	-55
262.5	6	-90
245.3	4	-78
234.4	6	-120
220.6	4	-151
210.0	3	-85
199.6	4	-156

Please be aware that the data shown on the Frequency Spectrum tab is provided so that you can make comparisons between different PE recordings. Applying different windows and/or sub sampling rates will cause these figure to change and it is up to the user to determine the optimum window type to use based upon their own requirements.

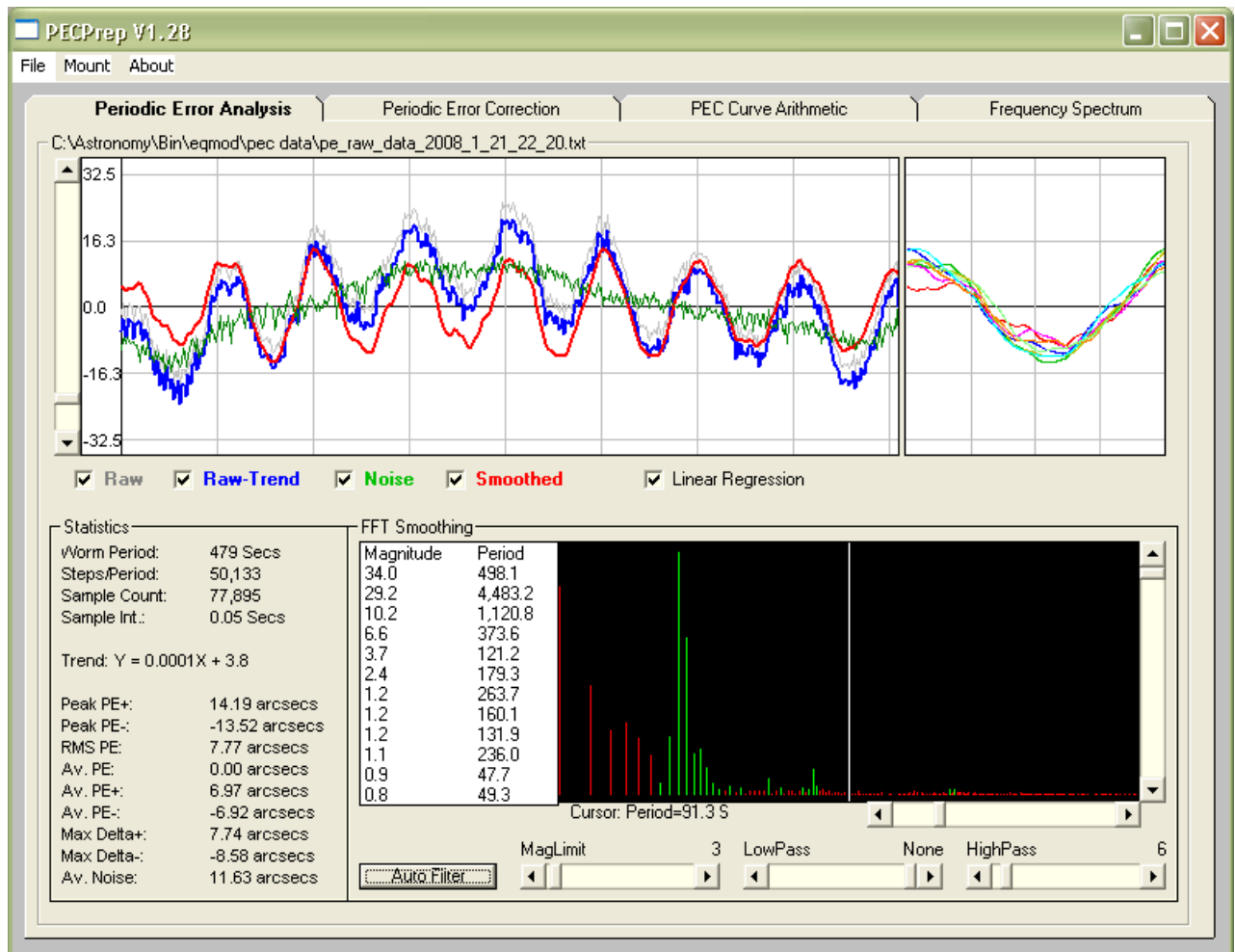
The underlying FFT model remains unchanged regardless of any viewing options selected on the Frequency Spectrum Tab and the accuracy PEC creation process is in no way affected.

EQMOD PEC Generation - worked example:



Here we have loaded some raw data, captured using peregrecorder.

The characteristic Periodic Error due to the worm period is quite evident however this appears to be superimposed upon a lower frequency signal. The effect of this is quite apparent in the stacked cycle display.

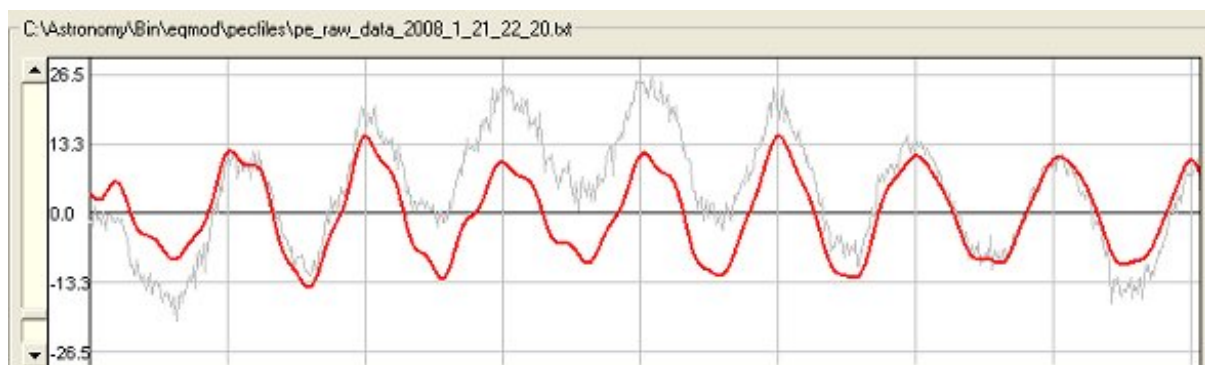


By using the Auto Filter button we can compensate for the low frequency component and remove some of the higher frequency noise.

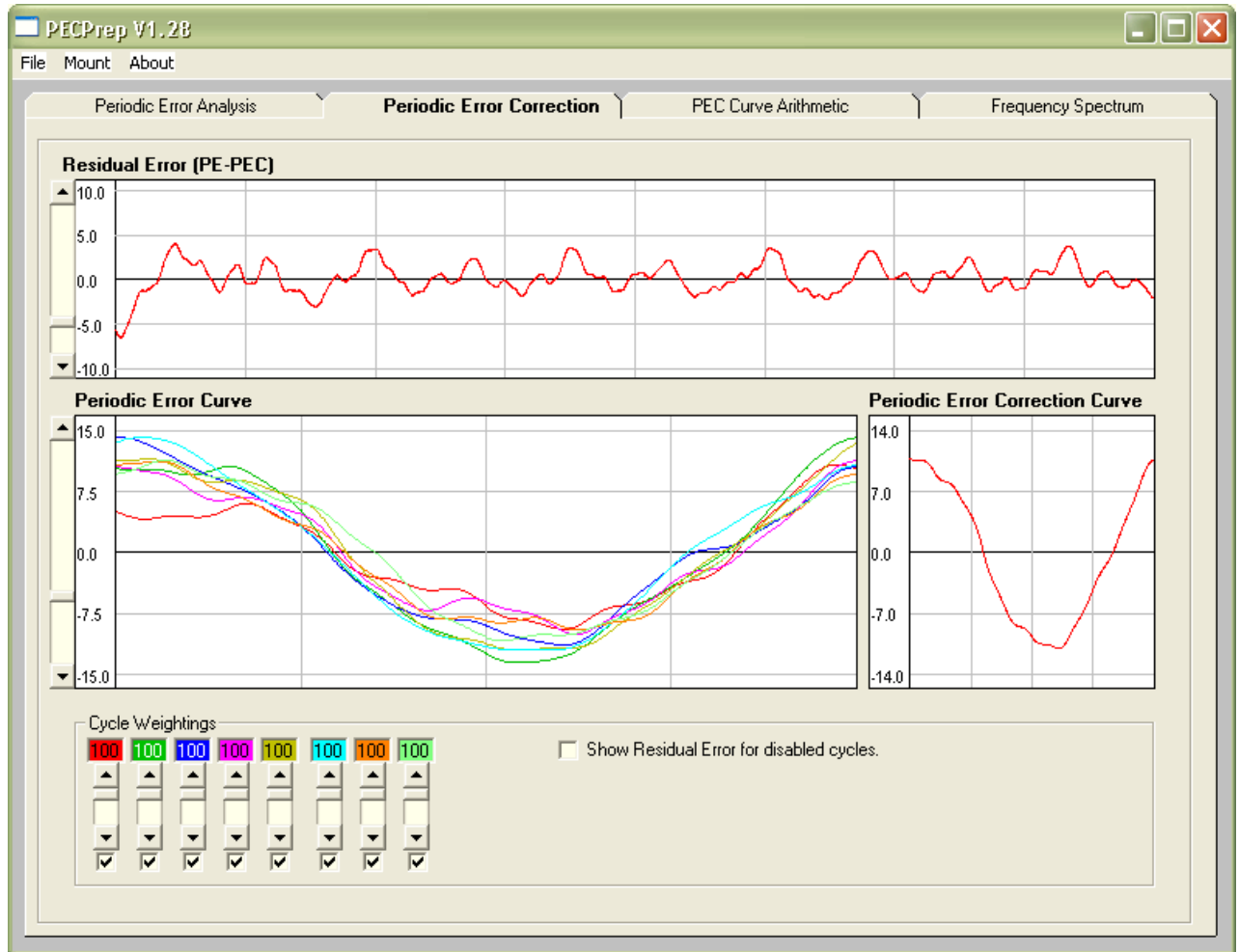
Use the frequency plot as a guide to ensure that no 'significant' peaks are filtered.

Notice how the stacked cycle display has changed. The individual cycles are in much better alignment.

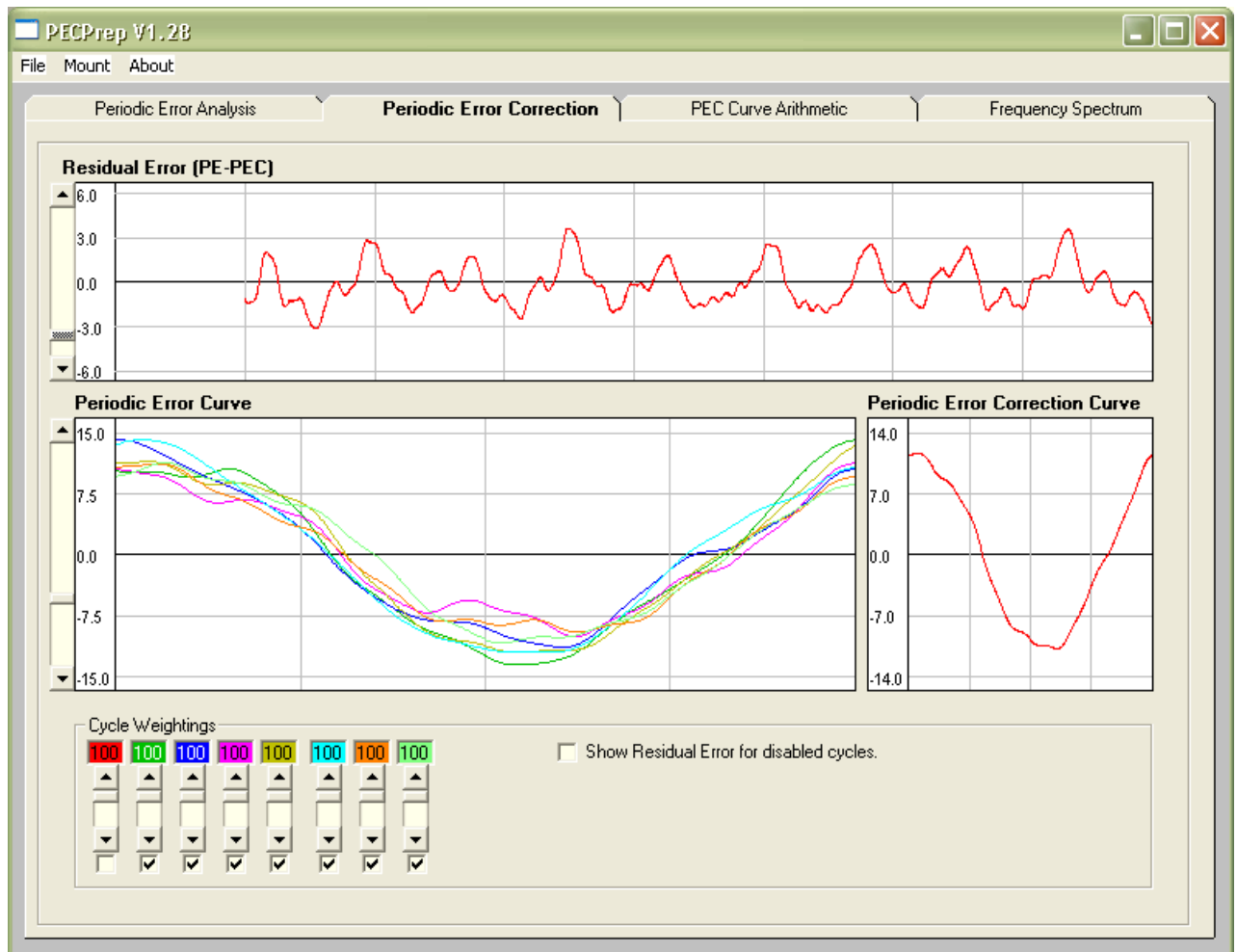
Here we can see the final smoothed data compared to the original raw data. Seeing and wind noise have been removed the data and low frequency signals removed to provide us with a signal where individual worm cycles can be selectively combined to produce a correction curve.



Now go to the PEC tab



The first cycle is clearly 'the odd one out' so remove it by unchecking its check box.



By combining all the other Cycles we can see that we could expect PEC to deliver a peak to peak error of around 6 arcsecs, a considerable improvement on the original 24 arcsecs.

When you're happy with the PEC curve save it via the file menu.

Periodic Error Simulations

To allow folks to investigate the behaviour of PE signals further and to carry out their own “what if” experiments PECPrep includes the ability to construct a curve from a PE simulation definition file. The file consists of a header line and a list of space separated values, each line defining a particular fundamental. This is the same format as the file produced when saving the data shown on the Frequency Spectrum tab.

```
Period Mag Phase PE
479 100 0 35
366.6 20 0 0
239.5 24 0 5.9
183.3 0 0 0
122.2 20 0 2
91.7 0 0 0
10.2 20 0 1
```

The magnitude parameter is not used. The PE parameter represents the Peak to Peak value in arcseconds.

On loading the file PECPrep will construct a simulated curve and save it to a new file (appending `_sim` to the original filename).

APPENDIX A: RA Axis Rotational Periods**Tables > EQ6Pro / Atlas EQ-G Gear periods**

Component <input type="checkbox"/>	Description	Period (Seconds)	No. Of Teeth	Comment
Stepper Gear	Gear attached to the stepper shaft, drives the transfer gear	122.2	12	
Stepper Gear Tooth	Contact period of each tooth	10.2	N/A	
Stepper Microstep	Period stepper stays at each microstep position	0.0095	N/A	sidereal rate is approx. 105 microsteps per sec
Transfer Gear	Gear between stepper and worm drive	366.6	36	
Transfer Gear Tooth	Contact period of each tooth	10.2	N/A	
Worm Bearing	Period of rotation of each ball within the bearing	170	N/A	
Worm Drive Gear	Mounted on Worm shaft	478.7	47	
Worm Drive Gear Tooth	Contact period of each tooth	10.2	N/A	
Worm Gear		86160	180	

Tables > HEQ5 / Sirius EQ-G Gear Periods

Component <input type="checkbox"/>	Description	Period (Seconds)	No. Of Teeth	Comment
Stepper Gear	Gear attached to the stepper shaft\, drives the transfer gear	122.2	9	
Stepper Gear Tooth	Contact period of each tooth	13.6	N/A	
Stepper Microstep	Period stepper stays at each microstep position	0.0095	N/A	sidereal rate is approx. 105 microsteps per sec
Transfer Gear	Gear between stepper and worm drive	380.2	28	
Transfer Gear Tooth	Contact period of each tooth	13.6	N/A	
Worm Bearing	Period of rotation of each ball within the bearing	225	N/A	
Worm Drive Gear	Mounted on Worm shaft	638.2	47	
Worm Drive Gear Tooth	Contact period of each tooth	13.6	N/A	
Worm Gear		86160	135	

APPENDIX B: Capturing PE Data

The purpose of this appendix is to give an overview of some of the underlying principles involved in capturing Periodic Error for import into PECPrep.

Choice of Equipment

The equipment you choose to use will determine your imaging resolution and as a consequence the resolution of the PE data recorded. If you can, capture data using your main imaging scope rather than a guide scope. If you have a webcam use that. Long exposures shouldn't be necessary as it should be possible to use bright stars. The aim is to capture as much data as possible and the short exposures and high frame rates provide by webcams make them ideal. If you don't have a webcam then other more specialist imaging devices can be used (depending on your choice of capture program) but opt for the shortest exposure time you can (whilst maintaining a well exposed image) - preferably ≤ 1 s.

Depending on your telescope you may need to use a focal reducers if the prime focus image scale is such that it is hard to keep the star in frame as it moves with the mounts PE and/or alignment drifts. Keep in mind that the capture period ideally needs to be at least 5 times the worm period of your mount. For an EQ6 this 40 mins, for an EQ5 54 mins.

Choice of Capture Program

The choice of capture program really comes down to the equipment you have and what applications you already have. If you have a CCD based webcam (such as those made by Philips) then you are recommended to use Perekorder. This application was developed specifically for the EQMOD Project and has been closely integrated to both the EQASCAM telescope drive and PECPrep.

For other camera types PECPrep supports the ability to import logs from many widely used guiding applications. Please note that during the capture process guiding itself should be off.

Star Selection

- The higher the declination the less movement that will be detected by your tracking program. As a result the movement data has to be corrected with respect to declination. Some capture programs do this themselves, whilst for others this is an option provided as part of the PECPrep import. As a result the resolution of PE becomes less at higher declinations. For optimal PE resolution a star with declination close to 0 should be chosen (where little or no compensation is required). However there may be other factors to consider.
- At declination 0 you will experience the maximum rate of drift due to any polar misalignment. For PE analysis this drift is irrelevant but its presence may restrict the amount of data you can capture data in the first place. For instance PHD has a limited search area of 50 pixels and if the target moves outside of this it will stop logging movement.
- The key point is to capture lots of data. So if you find yourself having to use a higher declination star simply to be able to capture 5 or more cycles then do it - the analysis results will be better than capturing just a single cycle at a lower declination.
- Avoid using a star that will track over the meridian during the data capture as balance shifts occurring may affect the nature of PE trace.
- You may want to start your PE recording in twilight and this can be done using a bright star. It doesn't matter too much if seeing conditions or the telescope hasn't cooled down as fluctuations in image due to those effects can be filtered from the data at a later stage.

APPENDIX C: Analysing PE Data

The purpose of this appendix is to give an overview of some of the techniques and underlying principles that can be applied when analysing Periodic Error data in PECPrep.

The first thing to understand is that the data the PECPrep imports shows the apparent movement of a star when your mount is tracking and the error signal produced is a summation of several effect.

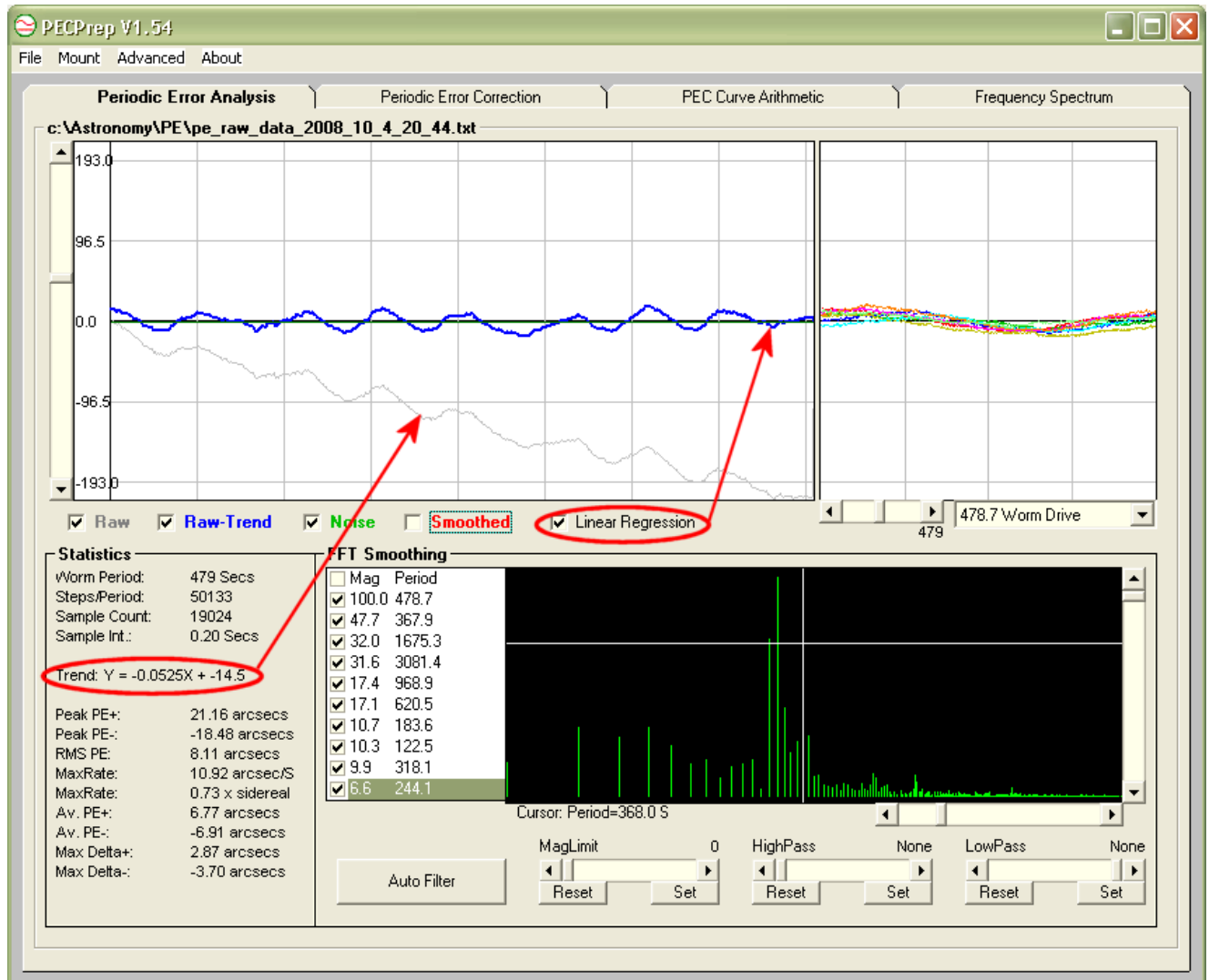
- Periodic signals that correspond to rotating components within the RA drive
- Linear drifts – tracking rate errors, or alignment induced.
- Non periodic high frequency “random” events such as seeing fluctuation, wind, bumps
- Non periodic low frequency effects due to balance shifts, movement restrictions (tight cables), loose clutches, flexure, mirror flop.

When folk mention periodic error they typically are referring to the error signal produced by the RA worm, and indeed usually this will be the most prominent periodic signal present. In reality however there are likely to be many other periodic signals present due to the gears and bearings used to drive the RA axis. The magnitude of error generated by each component can vary significantly between mounts, particularly with cheaper mass production mounts, and this can lead to a wide variety of responses.

The key to PECPrep's tracking error analysis is Fast Fourier Transform frequency analysis. This technique is able to break down a composite error signal into its component parts allowing the magnitude, phase and period of each to be assessed. Armed with the frequency analysis you can then decide what aspect of the tracking error you're interested in and use PECPrep's filters to isolate only those areas of interest.

It's important to appreciate that PECPrep's ability to provide accurate analysis is directly proportional to the quantity of data you give it. The more data the better. I would recommend that you capture data for at least 5 worm period cycles.

OK lets load some data into PECPrep and take a look at what we can deduce....

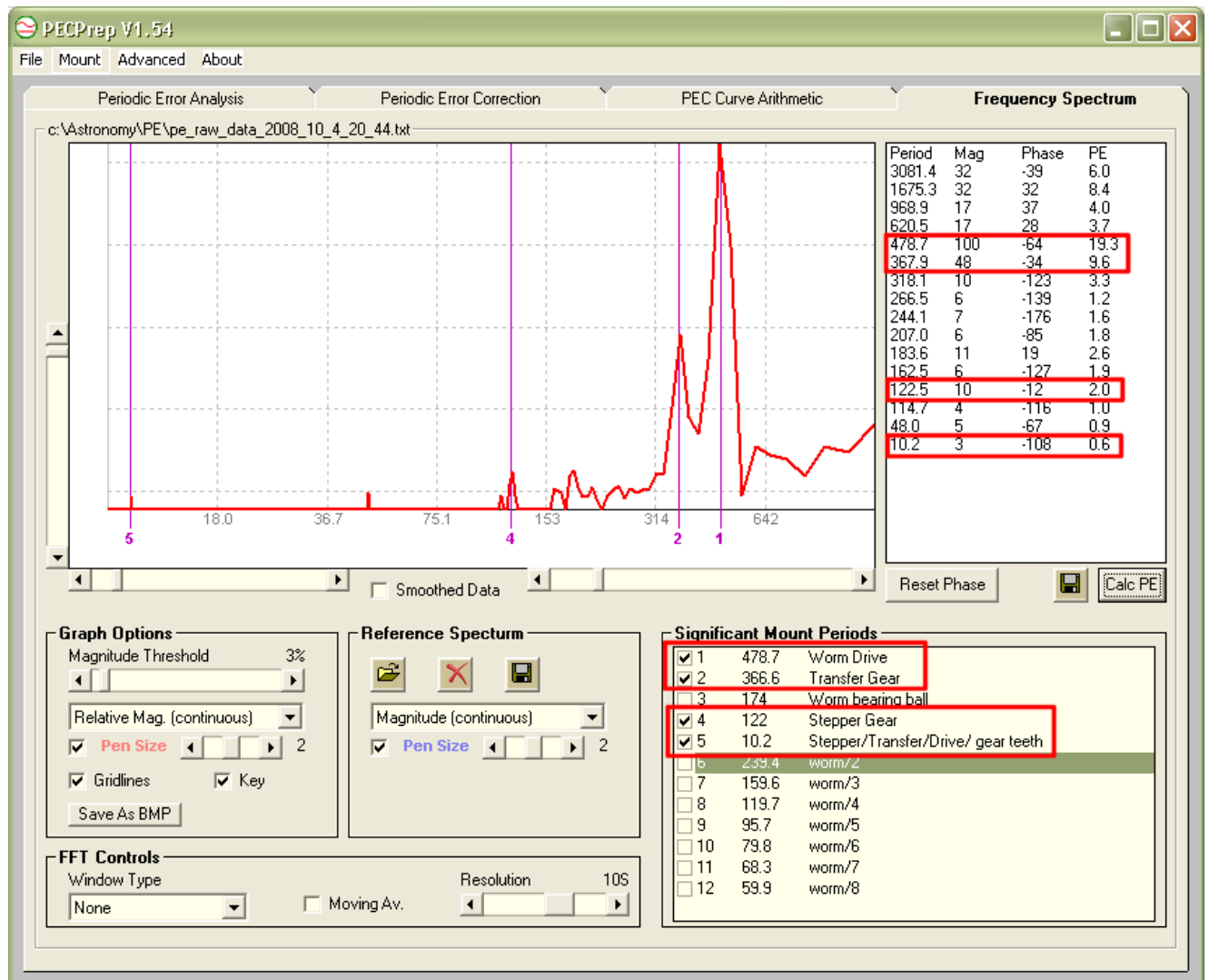


We can immediately see that the raw data (grey trace) has a linear drift associated with it. The trend given in the statistics pane shows:

$$Y = -0.525X + -14.5$$

This tells us that there is a constant drift present at a rate of -0.525 arcsecs per second. By checking the "Linear Regression" checkbox this drift is removed from the data to give us the blue trace.

First impressions are that the error trace is showing the expected "sinusoidal" response but to analyse this in greater detail we need to look at the Frequency Spectrum. This will allow us to identify the presence of signals due to the rotational periods of key components in the EQ6 RA drive and will allow us to decide if any further filtering is required.



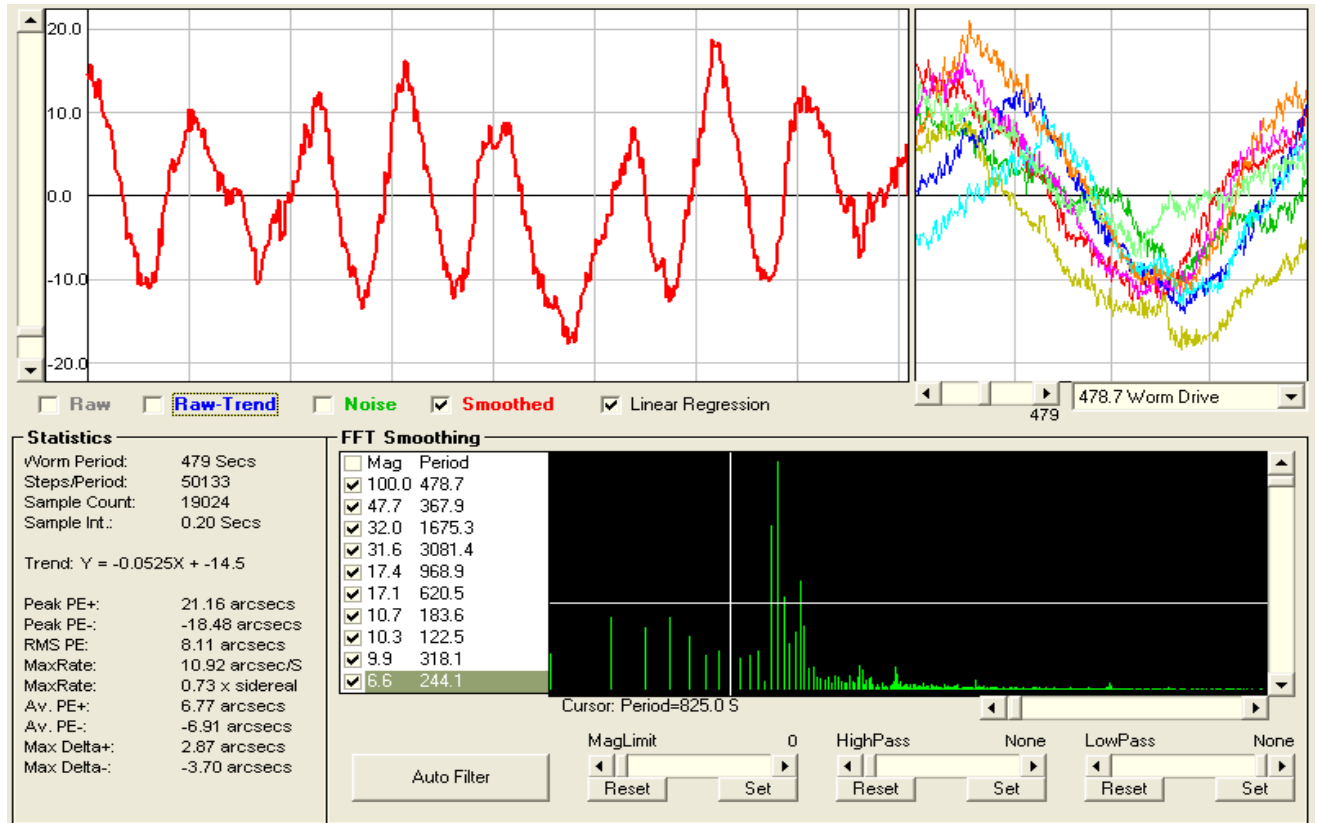
The frequency spectrum display contains a list of know “significant mount periods” for your mount and by clicking on the associated check boxes you can quickly find matches to peaks in the spectrum.

It is quite likely that in addition to peaks associated with the fundamental mechanical periods you will also see peaks associated with harmonics of those periods. So if a significant signal appears with a period of 300s we might also see harmonics at 150s (2nd harmonic), 100s (3rd harmonic), 75s (4th harmonic) etc. We would usually expect the signal magnitude to diminish with successive harmonic.

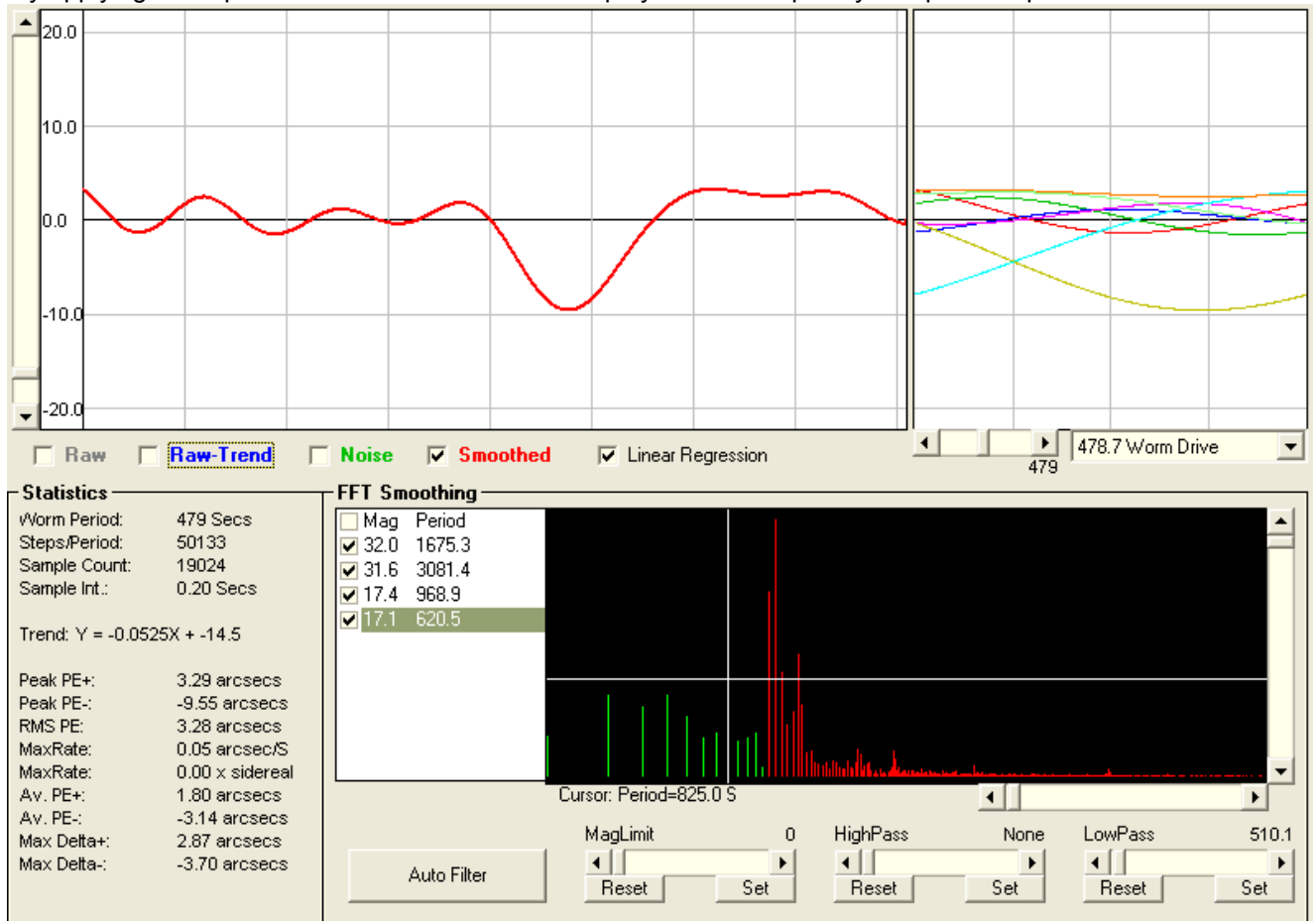
If you find that odd harmonics are particularly prominent this might indicate that the associated mechanical part is being restricted in its movement. (A signal consisting only of odd harmonics resembles a severely clipped sine wave)

In this case the most significant peak is clearly associated with the worm and contributes a signal 19.3 arcsecs peak to peak. Also significant is error induced by the transfer gear which contributes a signal 9.6 arc seconds peak to peak.

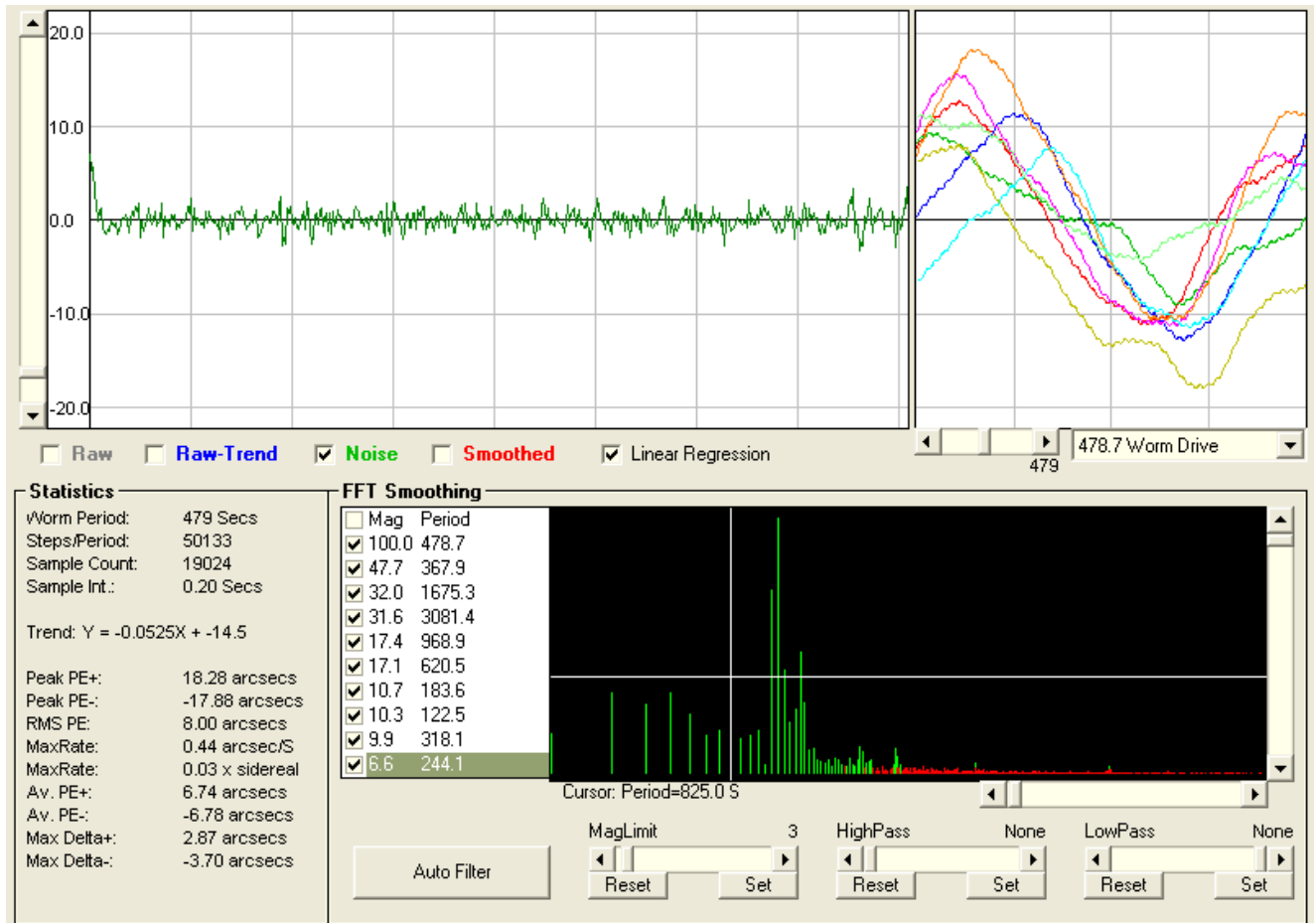
Returning to the Periodic Analysis Tab the combined error trace is



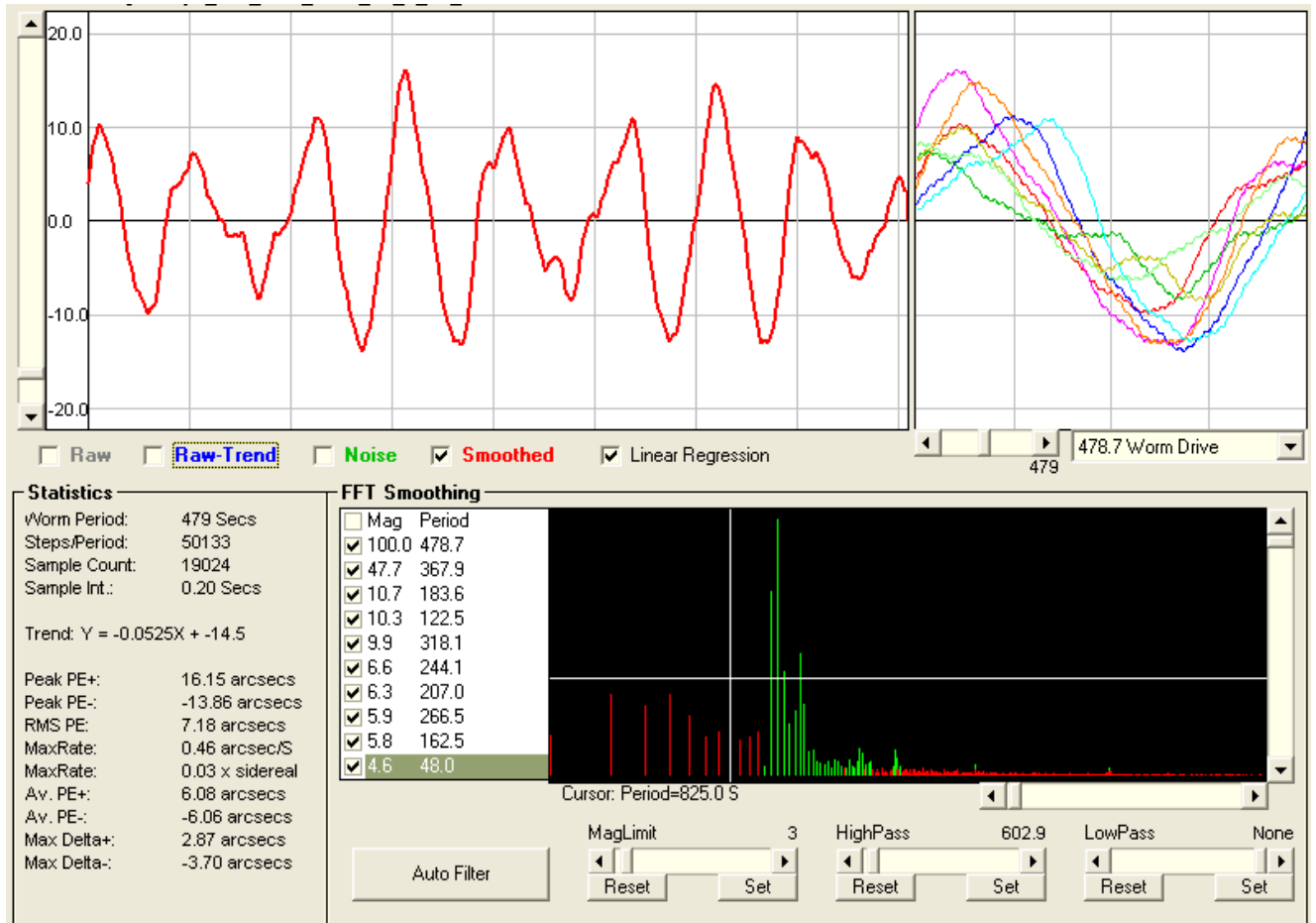
By applying a low pass filter we can isolate and display the low frequency components present.



By applying a magnitude filter we can isolate noise.



... and by using High pass and Magnitude filters we can isolate the error signal contributed by mechanical components of the RA Axis.

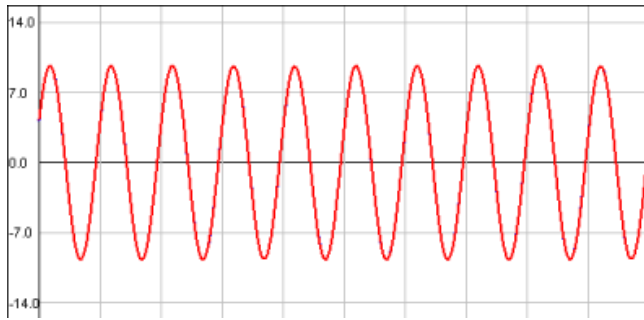


This trace is the Periodic Error of the mount. Just to recap, this is the tracing error caused by the mechanics of the RA axis. Drifts, noise and low frequency / non periodic signals have been removed.

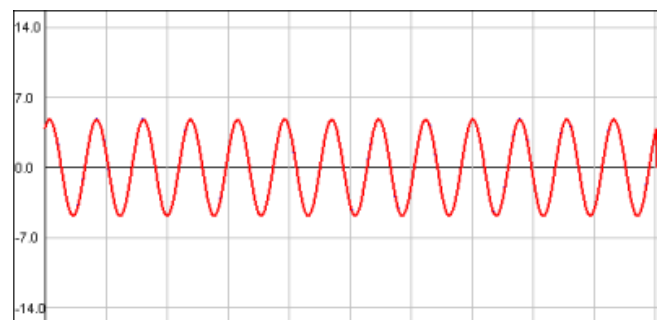
Looking at a trace you may be tempted to conclude that there is something fundamentally wrong with the tracking. Each cycle has a different profile and there are large variations in amplitude between successive cycles. The stacked cycle graph shows how the cycles do not line up particularly well and it appears to be a shift in phase throughout the captured data (each successive cycle curve is moving further to the right).

Actually this type of response is exactly what we would expect given the frequency spectrum results we previously noted. This apparently complex shape is caused by the interaction due to three error sources, the worm, the transfer gear and the stepper spur and the variations between cycles are due to the fact that neither transfer gear or stepper motor have rotation periods that are harmonics of the worm.

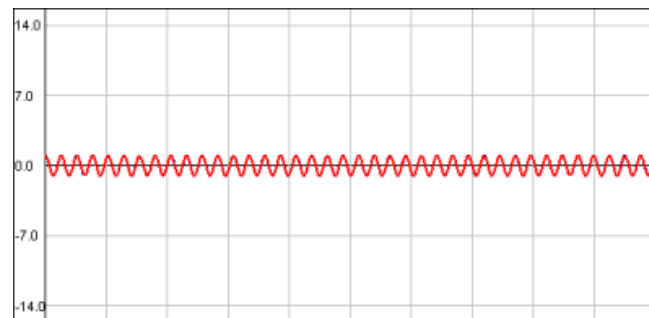
Hopefully the following illustrations (made using PECPrep's simulator feature) will make things clearer.



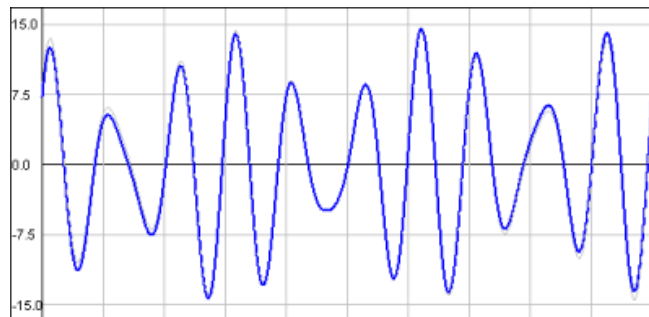
Worm
 Period=479 seconds
 Peak-Peak = 19.3 arcsecs
 Phase=-64 degrees



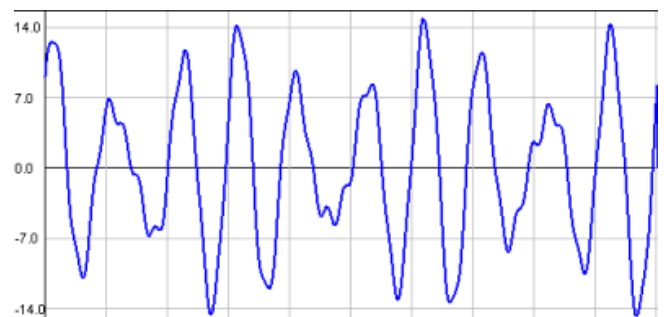
Transfer Gear
 Period =3 66 seconds
 Peak-Peak = 9.6 arcsecs
 Phase=-34 degrees



Stepper Spur Gear
 Period = 122 seconds
 Peak-Peak = 2 arcsecs
 Phase = -12 degrees



Worm + Transfer Gear



Worm + Transfer Gear + Stepper Spur Gear

The “red” graphs are the component signals whilst the blue graphs show the effect of adding those component together.