Gain From Using One of Process Control's Emerging Tools: Power Spectrum

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Process plants are starting to get big benefits from a widely available analysis tool: power spectral density. The power spectrum is used to analyze the frequency contents of a signal. The following examples demonstrate practical uses of Power Spectral to answer these questions:

- Is Control Improved By Tuning?
- Is Valve Life Extended?
- Is An Oscillation Hidden In The Noise?

We've also included an Overview of Different Ways of Viewing Power Spectrum.

Is Control Improved By Tuning?

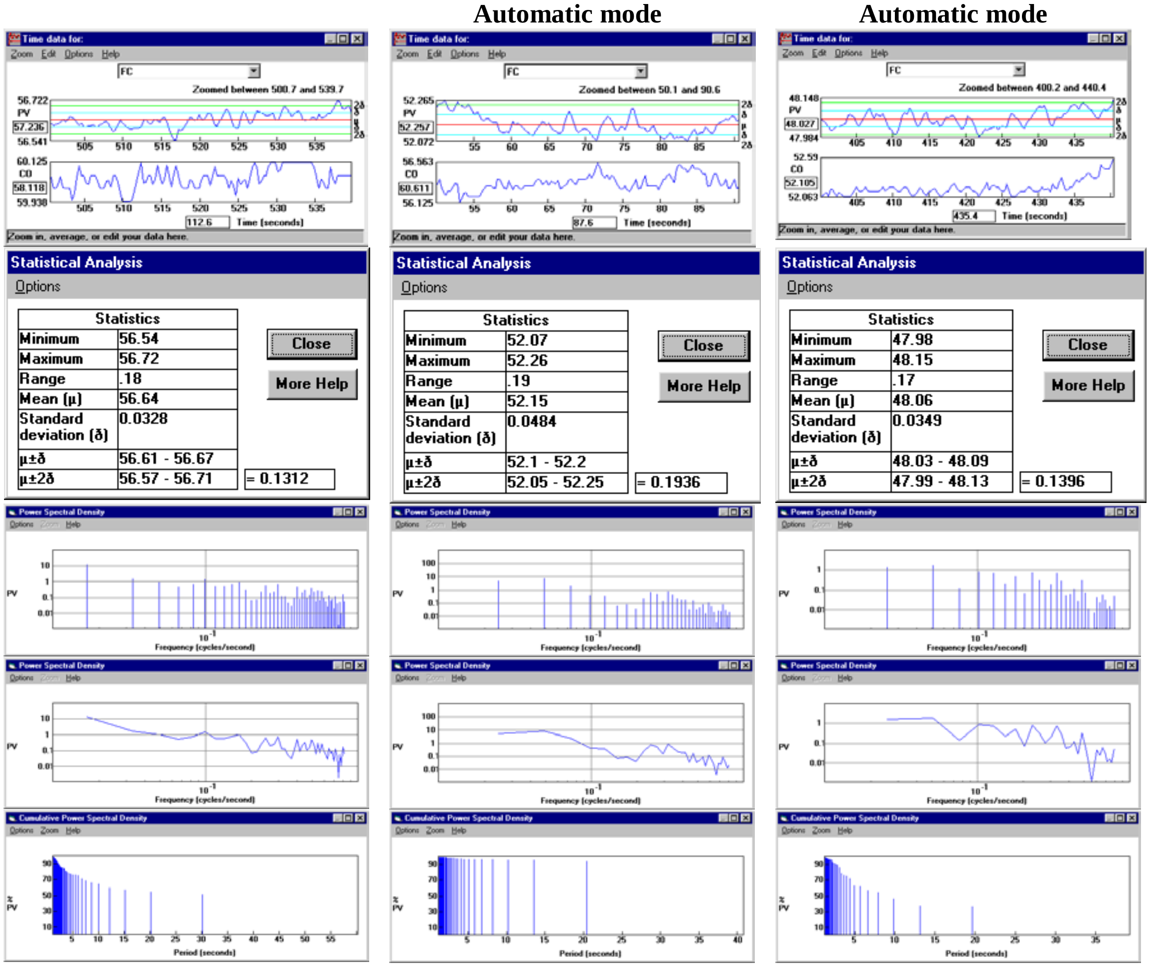
Power spectral plots are useful for seeing the improvement in response with the new tunings, without having to bump the system with a setpoint or load change. The objective is to keep the power at low frequencies and long periods as low as possible.

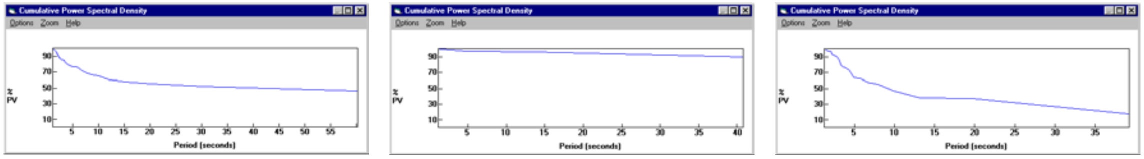
The below data was collected from a flow loop at a refinery. Compare this series of columns. Data collected in 1) Manual, 2) Auto with current tuning and 3) Auto with new tuning. The statistical analysis shows a small improvement in standard deviation from current to new, but manual mode has the smallest standard deviation. Statistical analysis does not always show the whole story on improvement. The power spectral plots show more.

Look at the fifth and sixth row of plots below. These are the cumulative power plots of the flow signal. The objective is to keep the power at high periods as low as possible. With current tuning, the power is almost flat across the spectrum. Manual control does a better job of keeping the power low at higher periods. The new tuning does the best job.

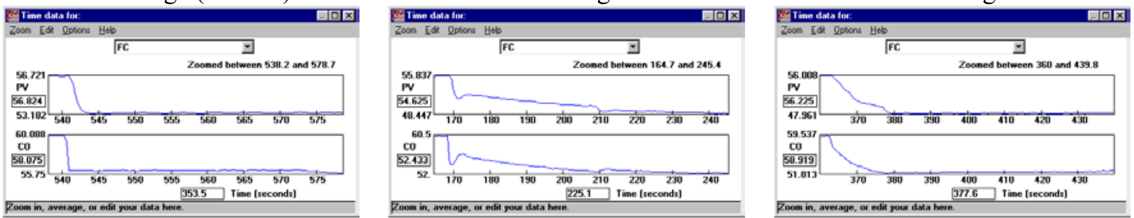
The third and fourth row show the power of flow and the log of power of the flow respectively. Notice the lower powers at low frequencies for new tuning. For current tuning, powers for frequencies less than .1 are about 10. For new tuning the powers for frequencies less than .1 are near 1. The objective is to keep the power low at low frequencies (high periods).

Manual mode | **Current tuning, Automatic mode** | **New tuning, Automatic mode**





CO change (manual) SP change SP change



A setpoint change confirms the power spectral data. The new tuning responds much better as the power spectral plots predicted.

Is Valve Life Extended?

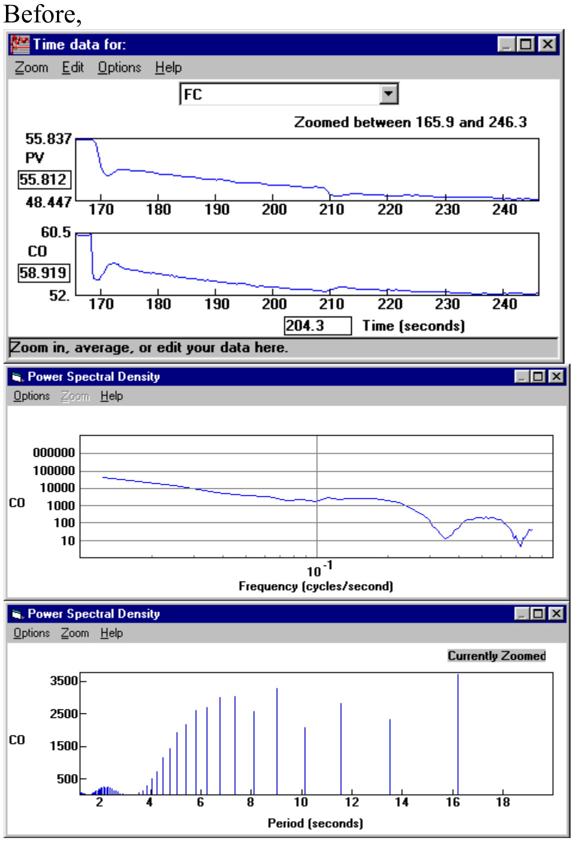
Displaying the power spectral density for the CO can help you determine if the valve effort has been reduced – increasing its life. Collect data from a set point change and/or from normal operation conditions in Automatic mode. The lower the power at high frequencies (short periods) the lower the effort required by the valve.

Set Point Change to Check Valve Life Extension

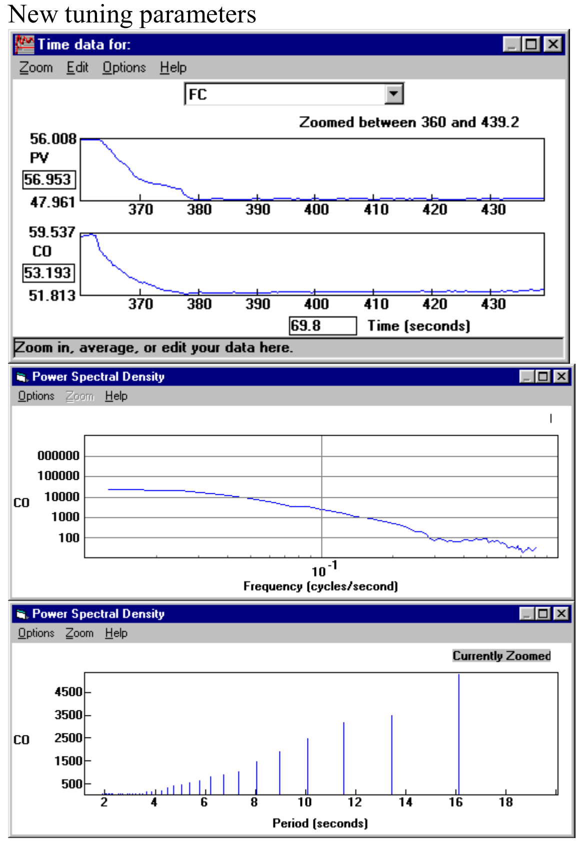
The following graphs are from the same loop as above. The power spectral plots were run on the controller output (CO). In the second row of plots the new tuning parameters show lower power use at high frequencies (toward the right on the graph). It is more dramatic and easier to see in the last row – another view of the same data. In the last row it is easy to see the power use at small periods is reduced (towards the left on the graph).

The life of the valve is increased with the new tuning parameters.

Before,

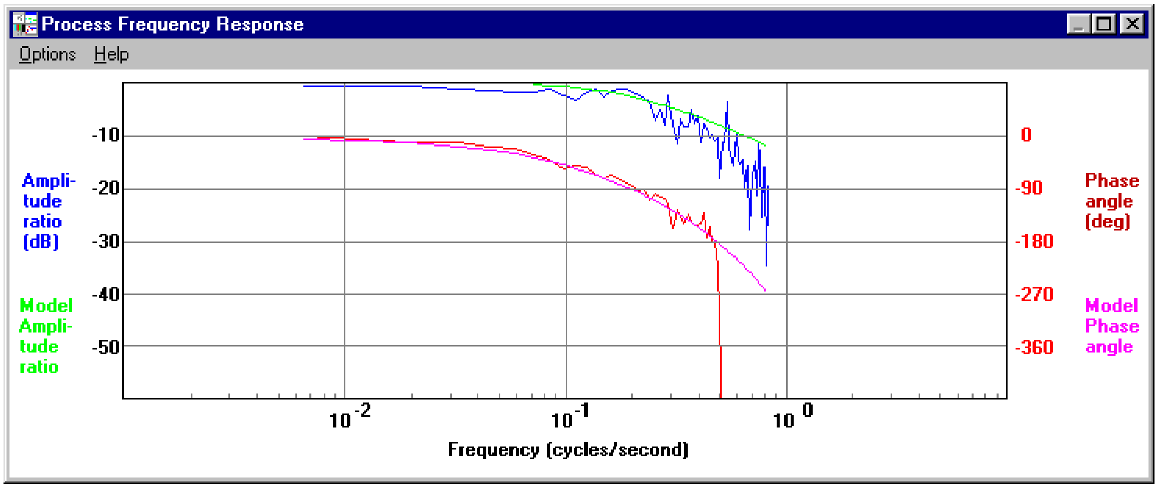


New tuning parameters



The new tuning parameters reduce the effort made by the valve. The valve life will be longer.

Bode plot for this process



Operation in Auto to Check Valve Life Extension

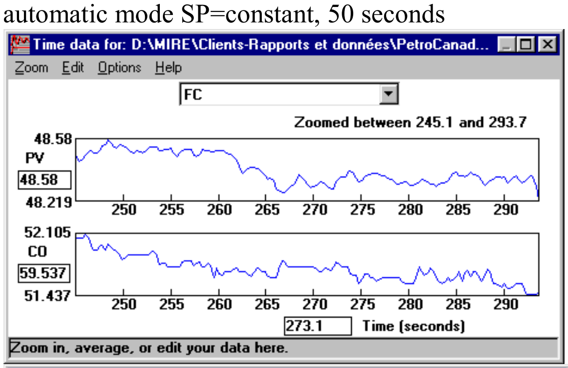
This data collected from same loop as above.

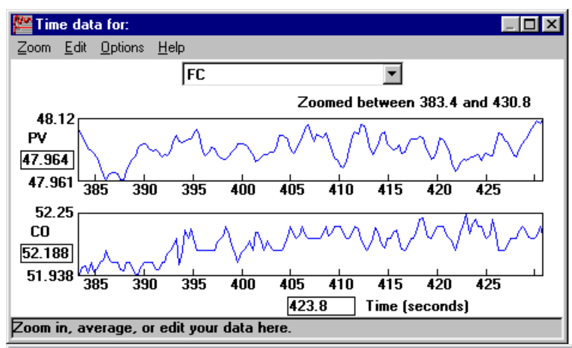
According to the Bode plot, if the tuning parameters are not aggressive, the bandwidth will be ~0.2 Hz (natural frequency is 0.4 Hz). All the frequencies over 0.2 Hz are useless (5s) if the SP does not change.

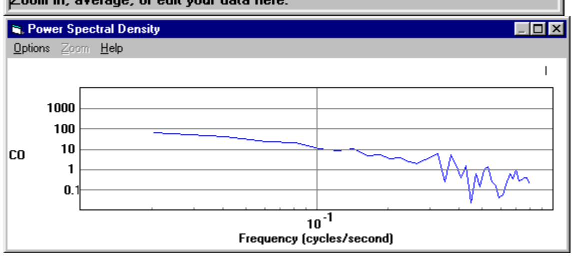
In the following power spectral plots, the power in the CO is greatly reduced from the new tunings. Notice that the vertical scale is much smaller in the power for the new tuning column.

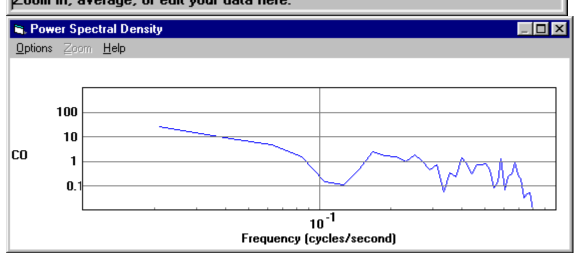
Actual parametes,
automatic mode SP=constant, 50 seconds

New tuning parameters

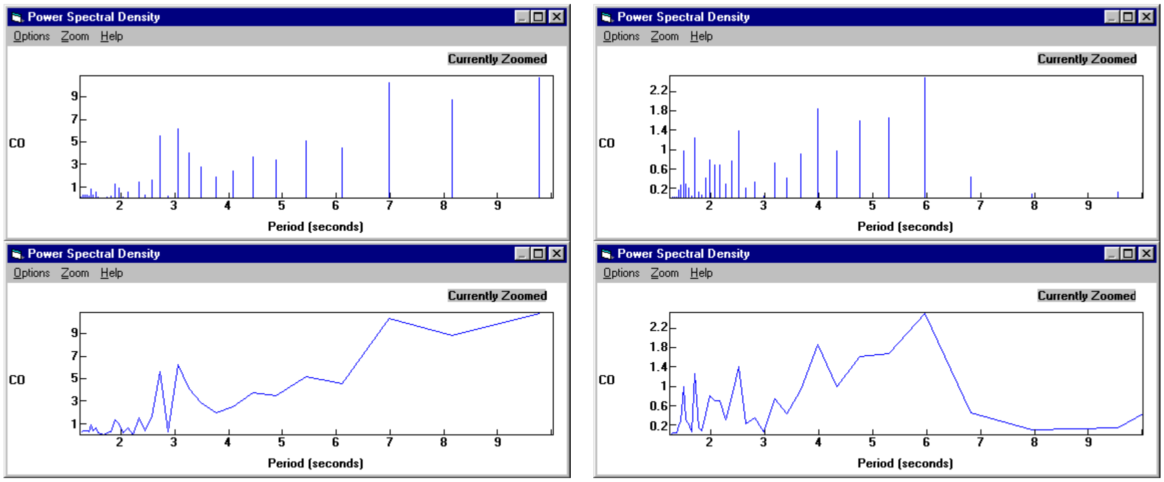








Short periods, high frequencies, mean this is noise, not disturbance rejection.


Power Spectral Density
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Power Spectral Density
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Period (seconds)

Is An Oscillation Hidden In The Noise?

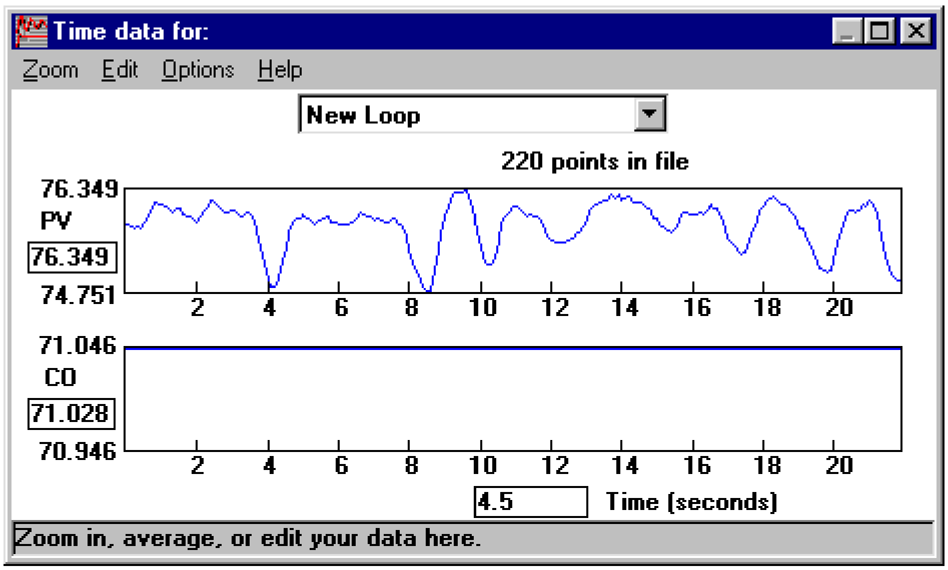
The power spectrum is an excellent tool to uncover hidden oscillations in a PV signal. An oscillation will appear as a peak in the power spectrum.

This peak will correspond to the fundamental frequency of the cycling. If the cycling is a sine wave, the peak will be the only noticeable frequency; but if the cycling is not a sine wave, there will be other peaks at multiple frequencies.

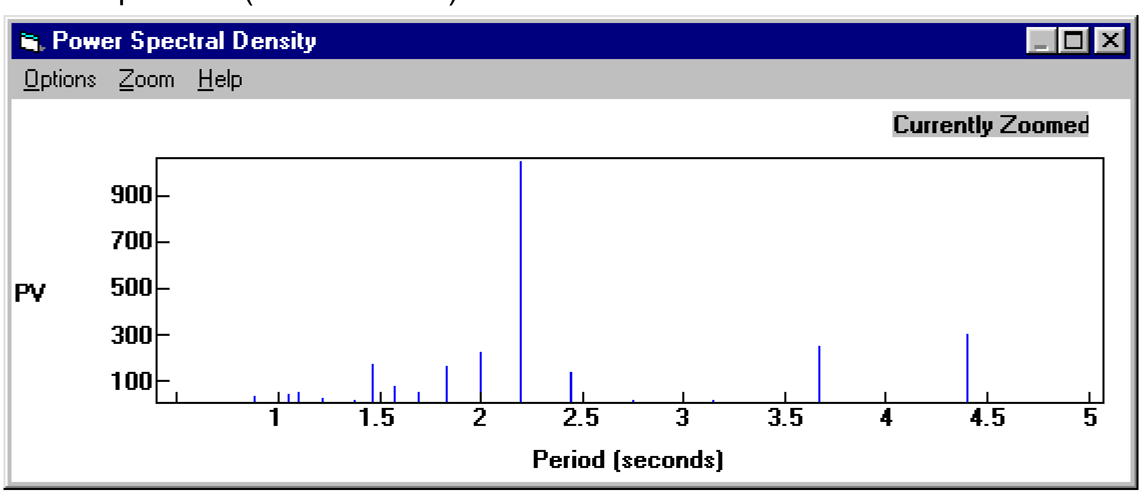
Sine wave in a flow loop

On the following flow loop, cycling is present and this cycling is clearly at a period of 2.2 s. The test was made in manual mode.

Time plot (manual mode)

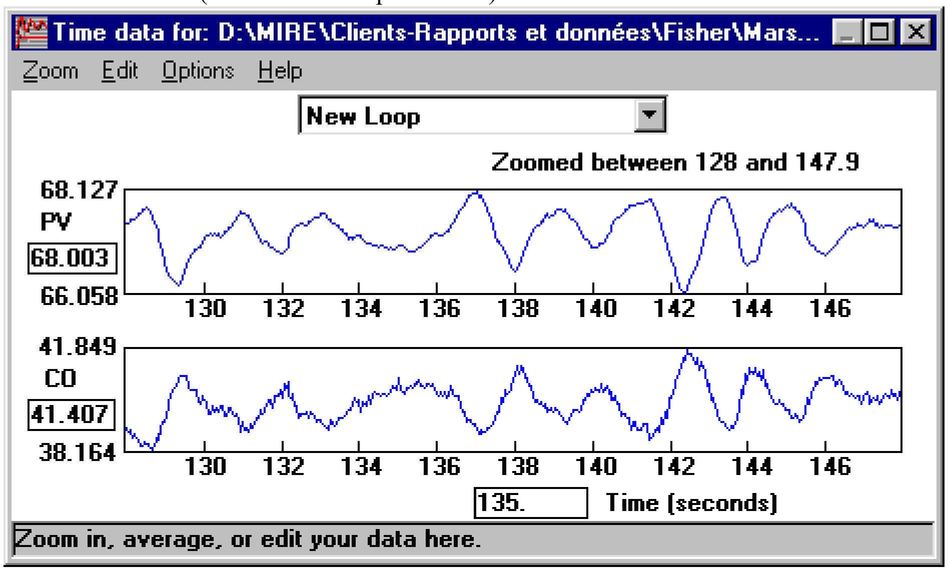


Power spectrum (manual mode)

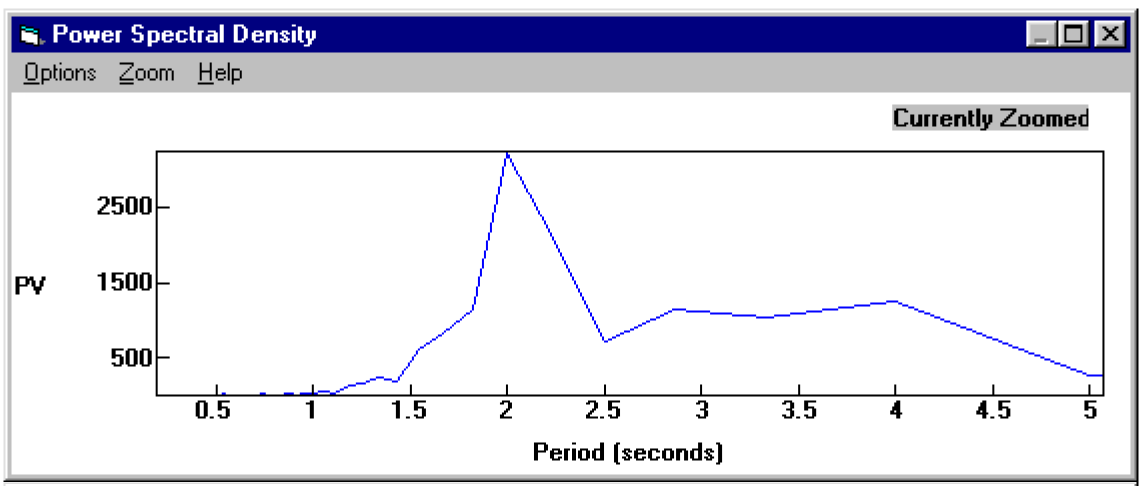


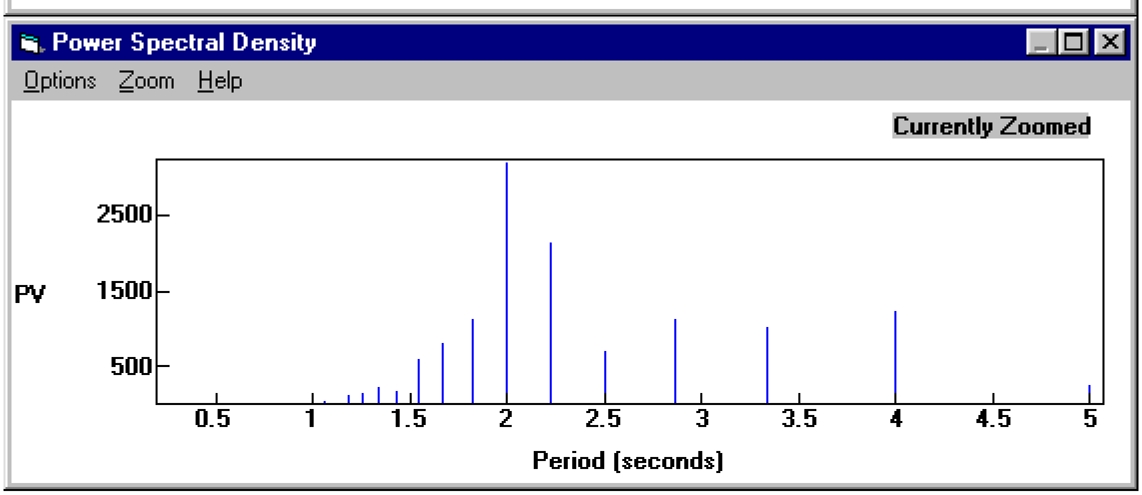
Time plot (automatic mode)

Another test done (on the same loop as above) in Auto mode:



Power spectrum (automatic mode)





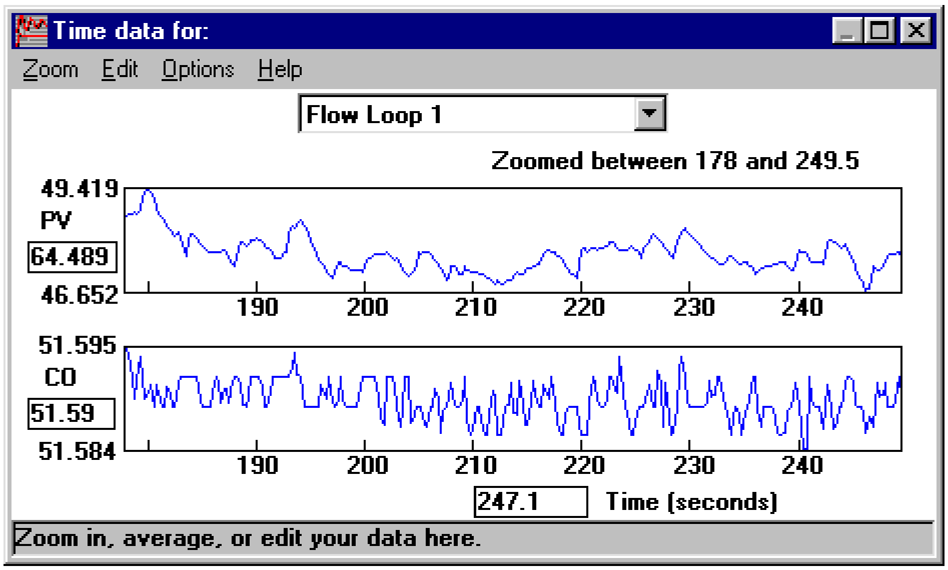
With the controller in auto, the power at about 2 seconds has increased from 1000 to 2500. Also the peaks near 2 seconds have grown. The controller has amplified the cycle and made it more pronounced.

The cycling is probably from the positioner and the frequency of the sine wave does not vary with the amplitude of the PV.

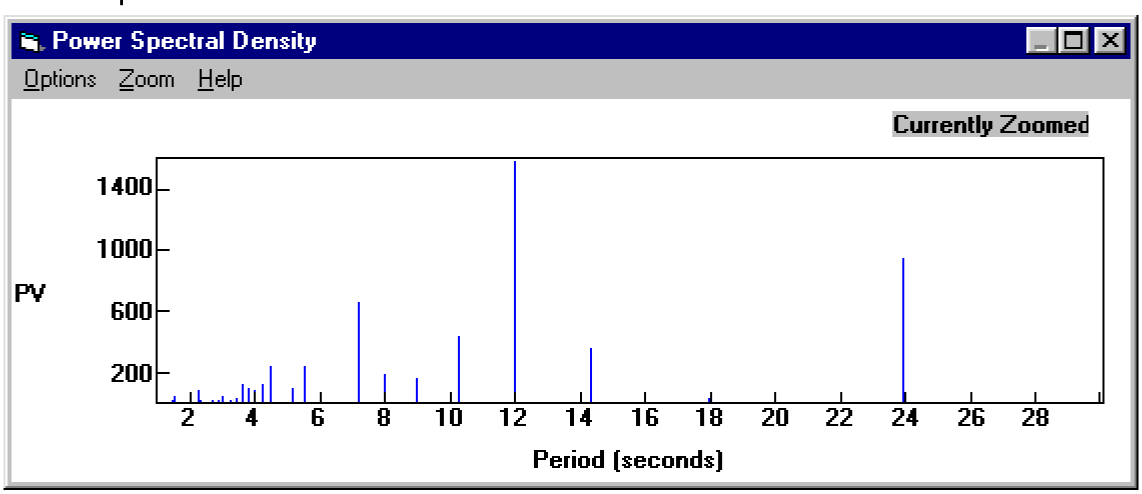
Non-sinusoidal cycle

Time plot

Multiple peaks occurring at harmonics in a power spectrum indicate a non-sinusoidal cycle. Find the lowest frequency peak and look for equipment cycling at that frequency. In many cases, the origin of these kind of peaks is another loop tuned too aggressively.



Power spectrum



Notice the peaks at 12 and 24 in this spectrum.

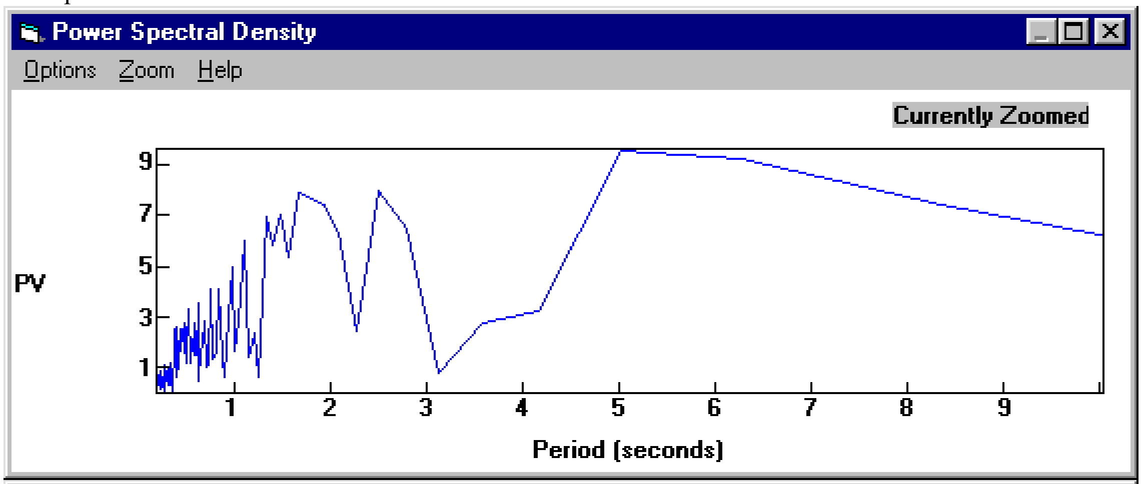
Overview of Different Ways of Viewing Power Spectrum

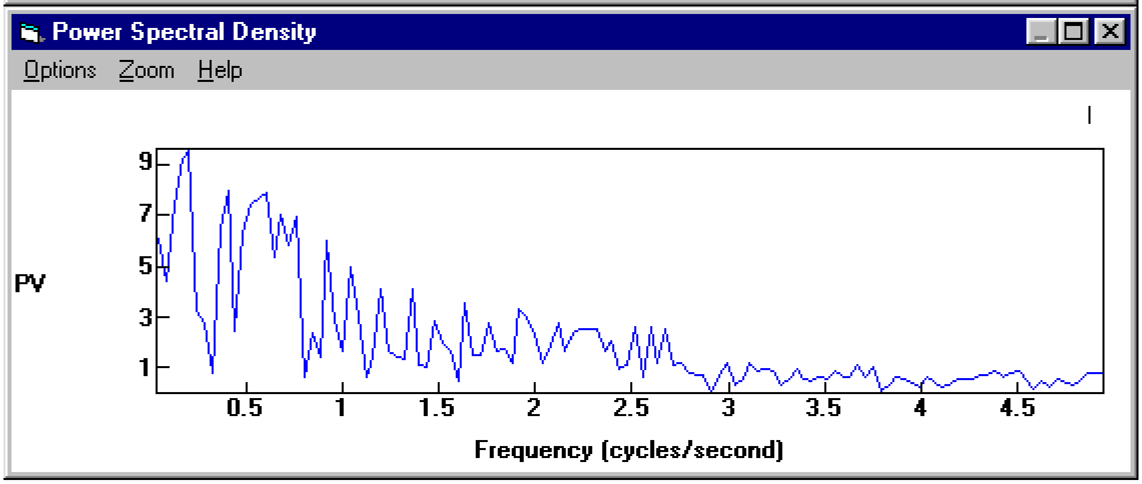
Lines or bar

Lines

The graph displayed with lines is useful for finding tendencies and trends. However it can be misleading if the distances between points is not constant. This depends on the frequency or X axis scale used. In this case bars can be the better viewing choice.

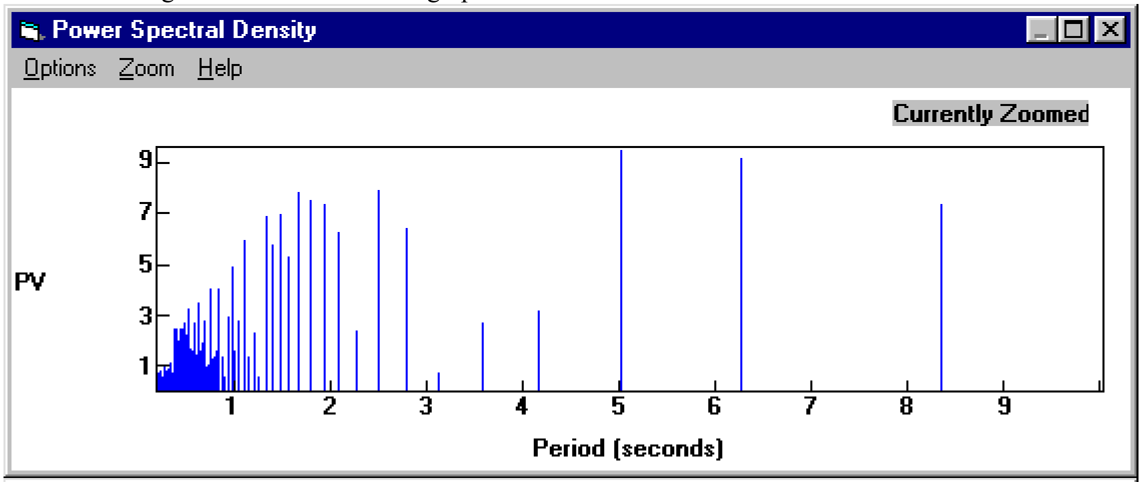
Example :

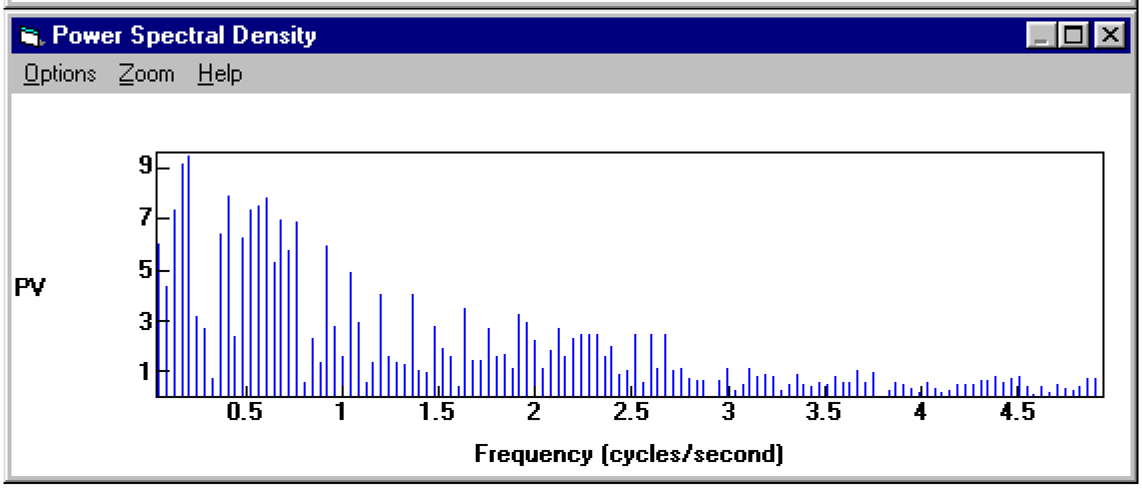




Bars

At the opposite, the bars are useful to see exactly where the points, the number of points, and the value for each in each region. Here are the same graphs as above shown with bars.

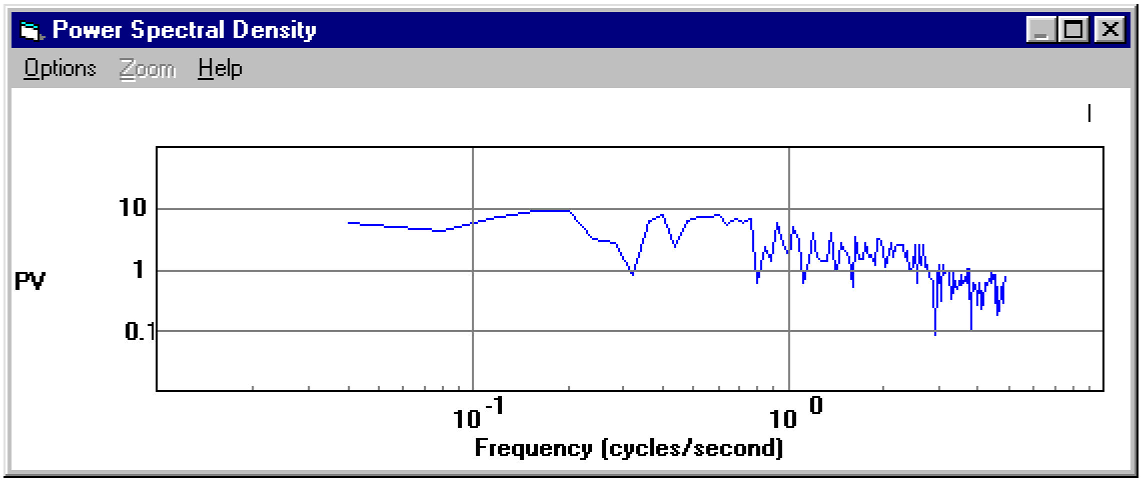




Logarithmic or linear?

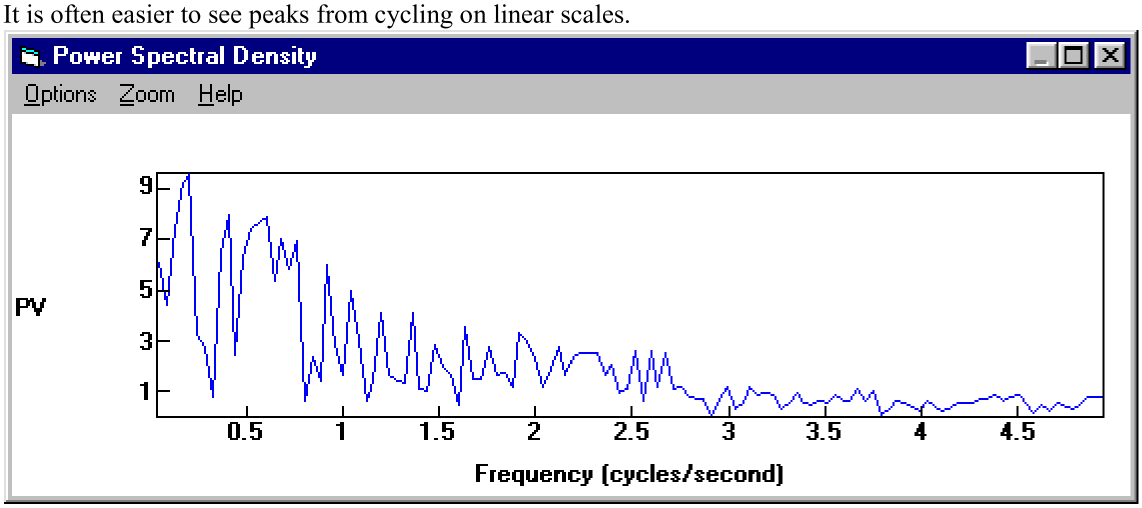
Logarithmic

The logarithmic display is useful to observe large and small amplitude signals at the same time. In the log scale, each frequency range has the same importance. Using a logarithmic display small signals are easily observable.



Linear display

It is often easier to see peaks from cycling on linear scales.



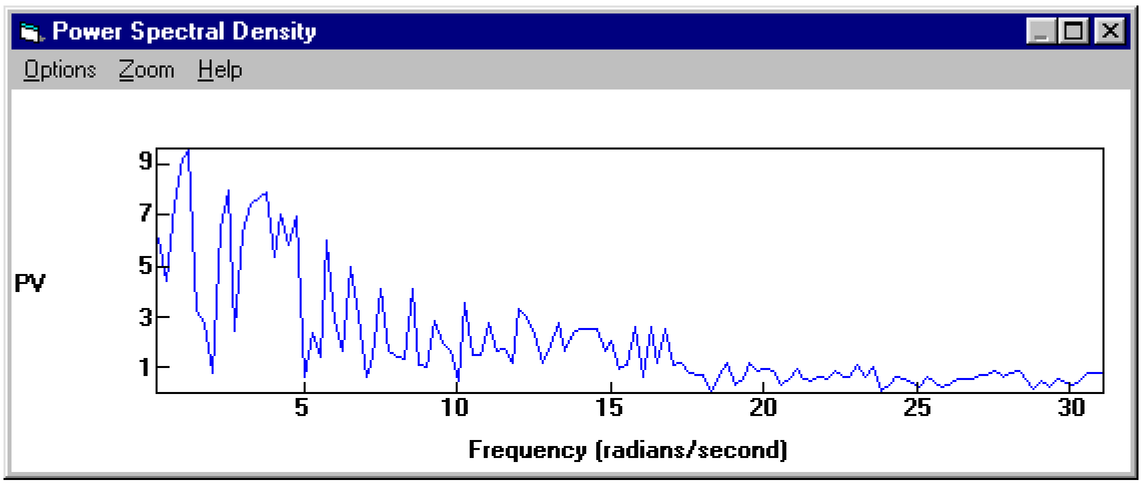
Frequency or time

Frequency (radians/s)

Process and controller time constants correspond well to frequency response plots using units of radians/time. So radians/time is a common unit for Bode plots and power spectrum.

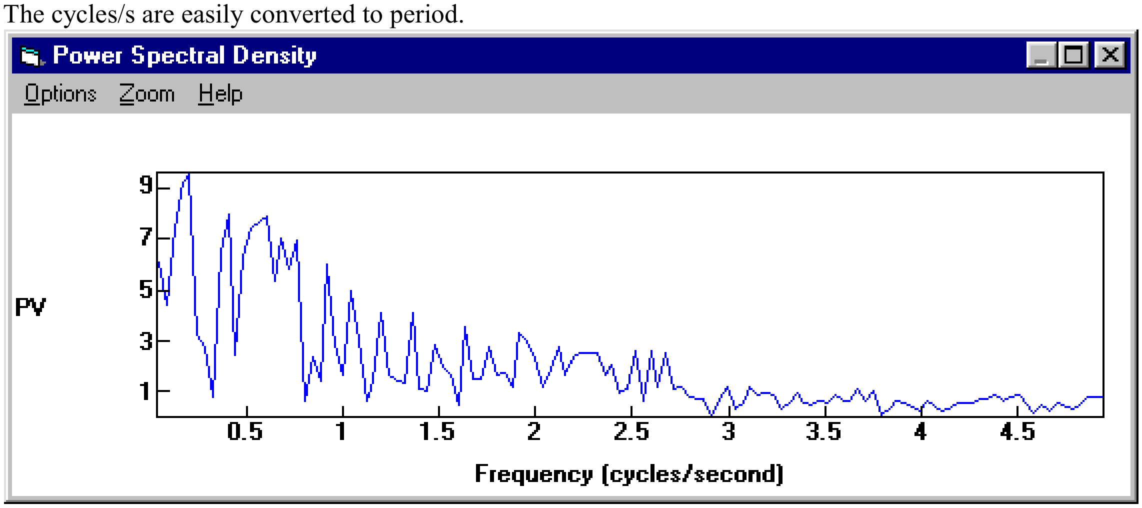
In Bode Plots, for first order time constants, the "corner frequency" is where the amplitude ratio starts to turn and the phase lag equals 45 degrees. Corner frequency is also called cut-off frequency. Consider a sine wave input to a process at this corner frequency. The output of a first order process will have half the input power at the corner frequency.

A lag time or first order time constant of 10 will have a corner frequency of 1/10. A PID controller with an integral time of 10 will also have a corner frequency of 1/10. A PID controller with a derivative time of 10 will have a corner frequency of 1/10 – however for derivative, this represents a phase lead of 45 degrees rather than phase lag.

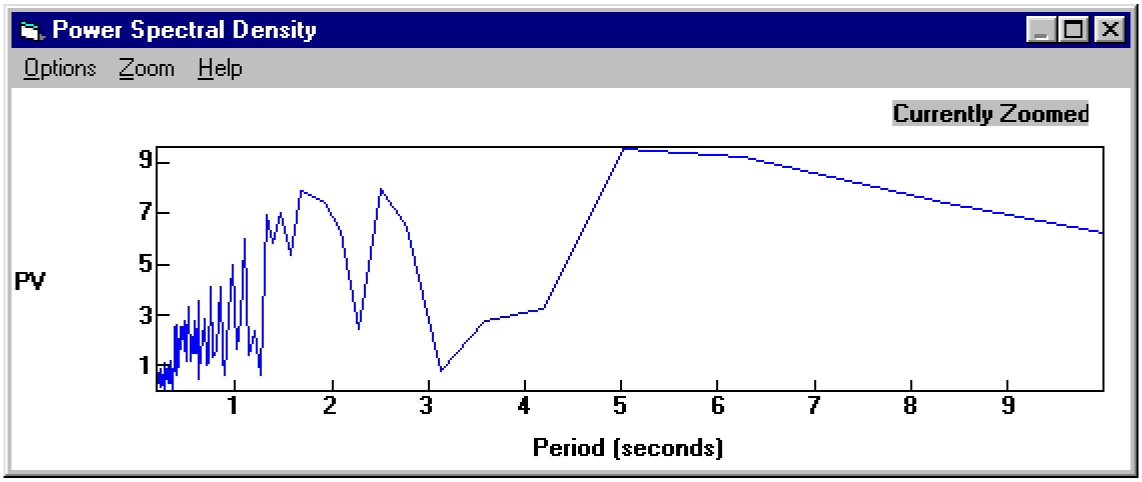


Frequency (Hz or cycles/s)

The cycles/s are easily converted to period.



Time


Power Spectral Density
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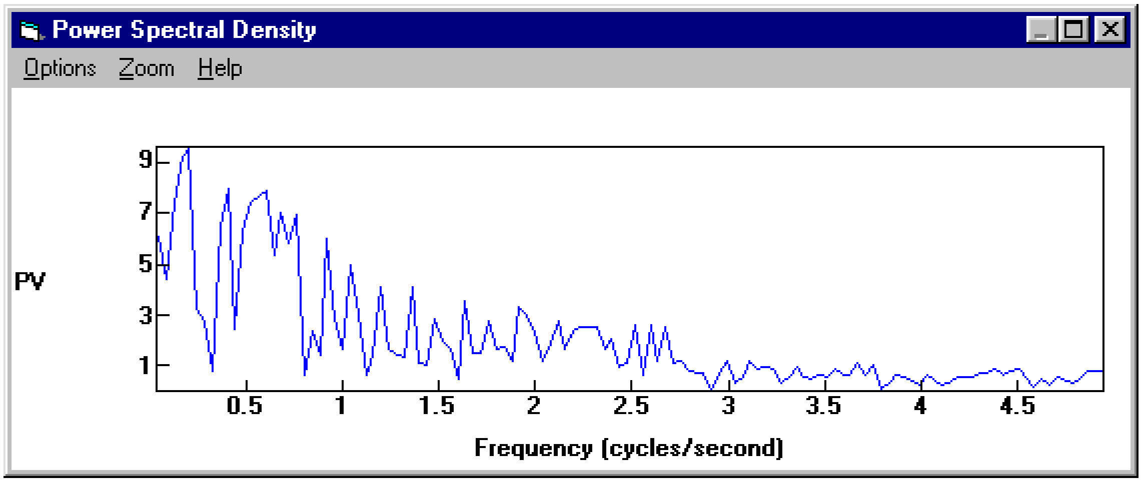
1 2 3 4 5 6 7 8 9
Period (seconds)

Power or cumulative power

Power



Cumulative power

Cumulative power is used to detect frequency ranges where the power increases. Also, it is useful to observe from which frequency the power stops to increase.