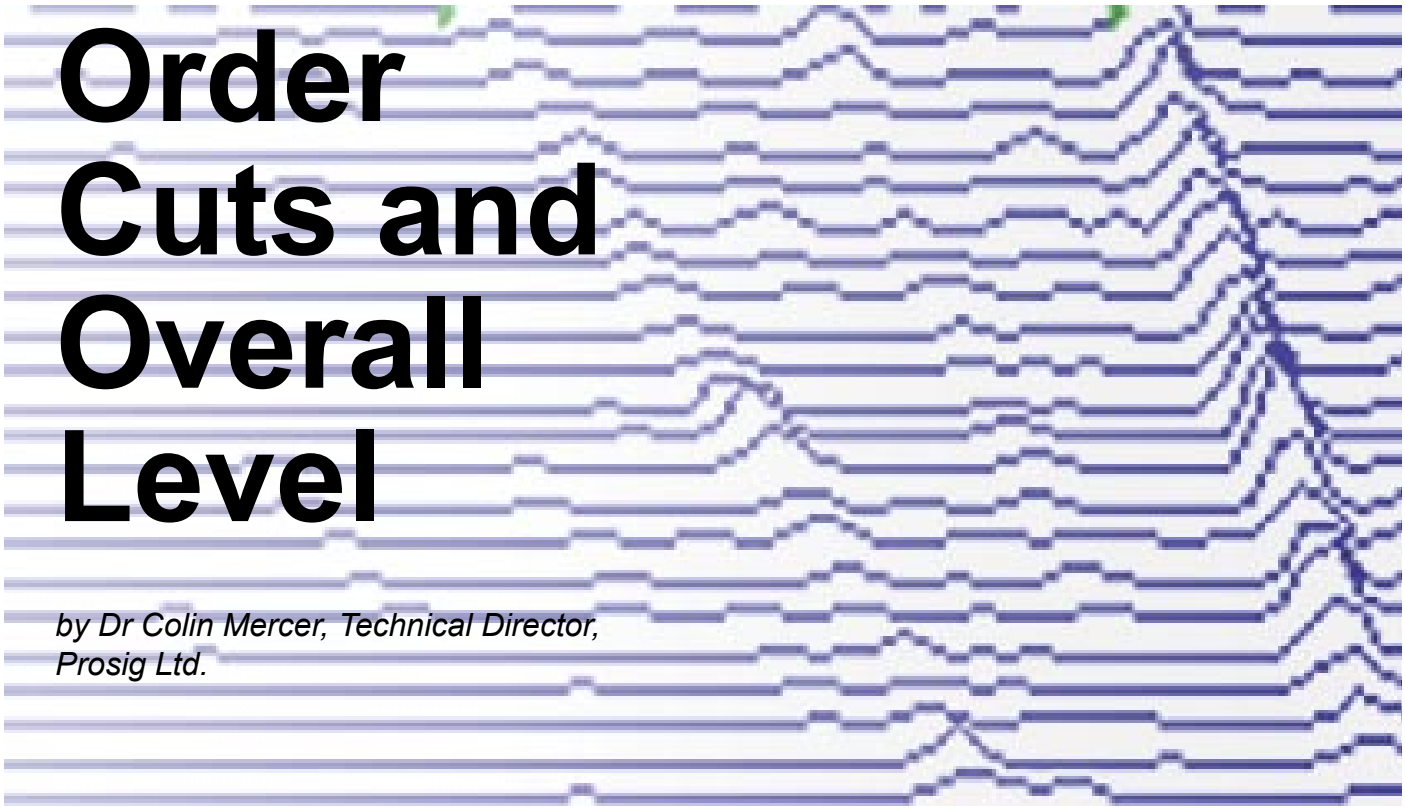
Order Cuts and Overall Level



by Dr Colin Mercer, Technical Director, Prosig Ltd.

Order cuts are taken from a set of FFTs, each one at a different rpm. The rms level is then found as the Square root of the Sum of the squares of each of the FFT values. Mathematically, if X_{ks} is the modulus (magnitude) of the k^{th} value of the FFT at speed s for $k = 1...N-1$ then the rms value at that speed is given by

$$rms_s = \sqrt{\sum_{k=o}^{N-1} X_{ks}^2}$$

This takes into account the entire energy at that speed both the order and the non order components, including any noise.

Graphically, suppose we have a waterfall such as shown in figure 1.

Extracting the FFT at, say, 4200 rpm gives the graph shown in figure 2.

The rms considers all of the energy in the entire spectrum. That is, in the graph in figure 3, it considers all of the blue shaded area. All the values are squared, summed and the result is square rooted, which gives the rms value.

When one is finding the order values we know that because the speed is changing the actual order will have been skewed over several frequencies. Also if is extremely unlikely that the frequency values at which the FFT was evaluated

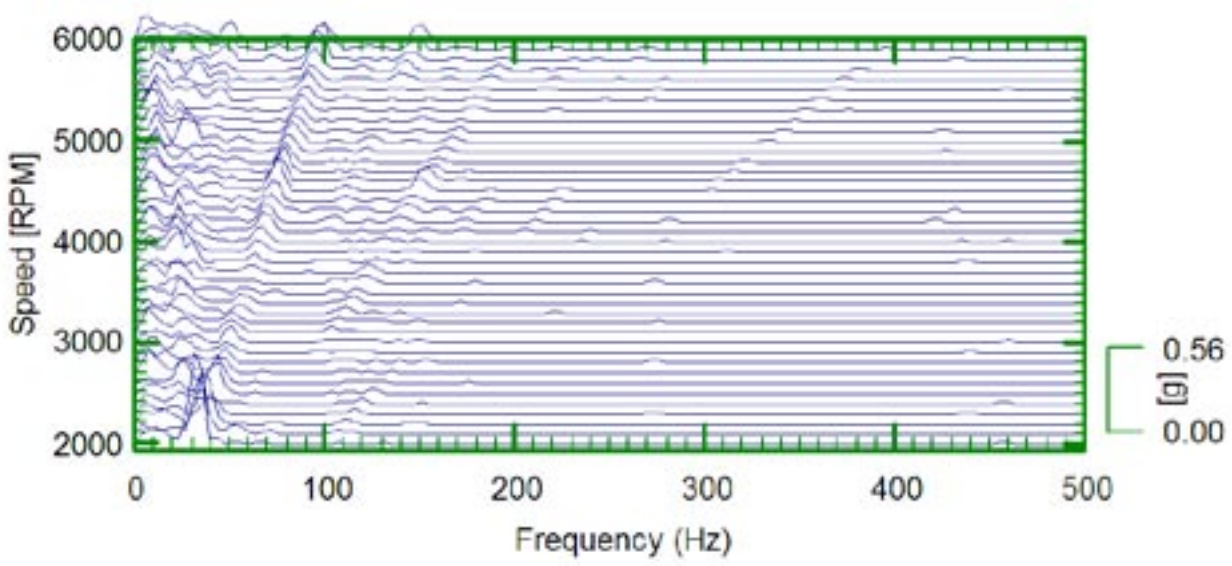


Figure 1: Waterfall Plot

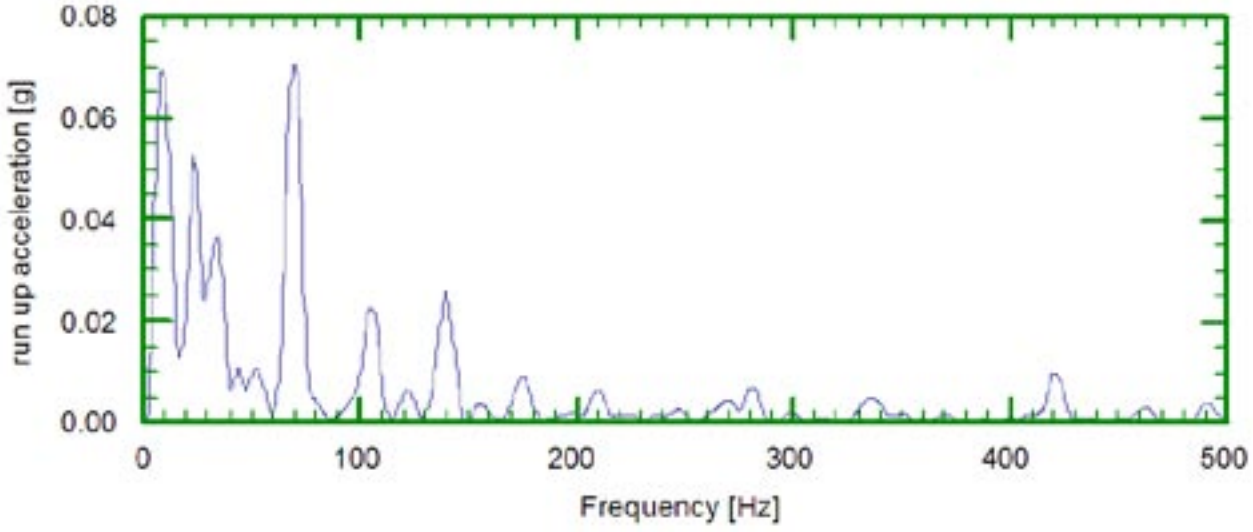


Figure 2: Frequency Spectrum

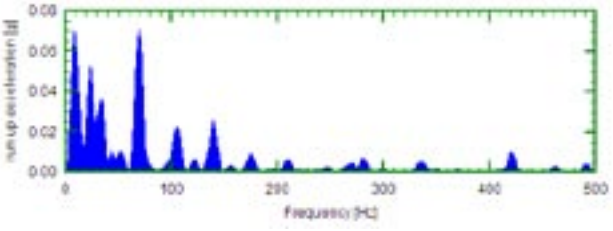


Figure 3: Shaded Spectrum

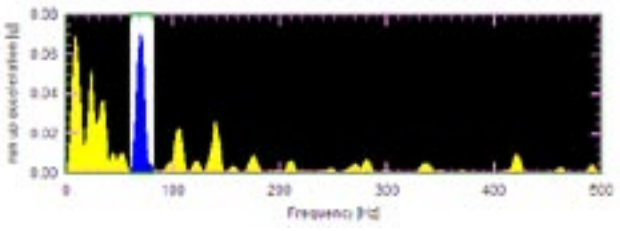


Figure 4: Shaded Spectrum (highlighted section)

will exactly match the frequency of the order at that speed. The FFT spectrum thus suffers from leakage as well as smearing. The net effect of both of these artefacts is that the spectrum is "broadened and flattened". That in the energy is now distributed over several frequencies so that once again one has to use a square root of sum of squares approach to determine the rms level centred over the frequency range of the order. This frequency range is usually referred to as the order bandwidth. Taking the peak valve will be grossly inaccurate.

Mathematically then we have that the component of Order *j* at speed *s* is given by

$$Order_{js} = \sqrt{\sum_{k=j-b}^{j+b} X_{ks}^2}$$

where *b* is the half bandwidth. The actual implementation is a little more sophisticated than above, but the signal processing essence is as shown.

Again, graphically, we now consider only part of the spectrum centered at the order frequency and over a finite bandwidth.

For a specific order we would only consider the blue part as illustrated in Figure 4. Once again all the "blue" values are squared, summed and the result is square rooted, which now gives the rms value of that specific order at the selected speed.

Now if we take all of the significant orders, square, sum and square root them, then we will have an estimate of the rms value. If the orders are well spaced then we will miss some of the noise and the very small orders. So we would expect the rms calculated from the orders to be smaller than the overall rms value. Note that the correct way of collecting the orders together is the square root of the sum of squares. Adding the orders together directly will give an incorrect value.

This is not the end of the story because sometimes the bandwidth of the individual orders overlap so that some energy is counted twice. In this situation the rms calculated will be greater than the true rms. If this occurs then we know we have had order bandwidth overlap.

For reference, one may be used to seeing the rms value calculated from time series. When computing the value from the time series, a division by the number of values in the summation occurs. This division does not occur if we are computing the rms from the frequency spectrum. Mathematically, if x_j is the time series and X_k is its Fourier transform then we have

$$rms = \sqrt{\frac{\sum_{j=0}^{N-1} x_j^2}{N}} = \sqrt{\sum_{k=0}^{N-1} X_k^2}$$

Dr Colin Mercer

Colin Mercer is the Technical Director of Prosig and has prime responsibility for signal processing and its applications. He was formerly at the Institute of Sound and Vibration research (ISVR), Southampton University where he founded the Data Analysis Centre. He is a Chartered Engineer and a Fellow of the British Computer Society.

Prosig Hardware & Software Used in This Tutorial

P8012 / P8020 Data Acquisition System

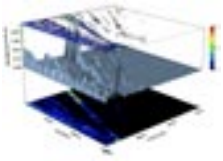
- **P8012 - 3 card chassis**
  P8020 - 5 card chassis
- **Configurable channel options**
- **24-bit precision**
- **Up to 100k samples/sec/channel (24bit)**
  Up to 400k samples/sec/channel (16bit)
- **Up to 20 analog channels plus tacho**
- **102dB dynamic range**
  -120dB noise floor

The P8012 supports 12 high speed analog inputs plus one digital tacho. The P8020 supports up to 20 high speed analog inputs plus two tachos. Units can be stacked to expand the system up to 80 channels. Various input options are available. These include high speed analog, low speed analog, thermocouple, strain gage, high speed tacho, CAN and GPS. Each option is complete with programmable signal conditioning, which is controlled by the DATS™ software.

P8012 / P8020 systems	
03-33-8012	12-channel (3 card) chassis. Includes • P8012 chassis • PC to P8012 USB 2.0 communications cable • Mains power supply for P8012 • In-vehicle power cable for P8012
03-33-8020	20-channel (5 card) chassis. Includes • P8020 chassis • PC to P8020 USB 2.0 communications cable • Mains power supply for P8020 • In-vehicle power cable for P8020
Select any combination of the following cards up to a maximum of 3 cards (P8012) or 5 cards (P8020)	
03-33-8402-B	4 high speed analog channels (BNC) *
03-33-8404-L4	4 high speed analog channels with programmable excitation (4-pin Lemo) *
03-33-8404-L6	4 high speed analog channels with programmable excitation (6-pin Lemo) *
03-33-8408	8 thermocouple channels
03-33-8409	8 analog channels
03-33-8420	4-channel tacho/frequency card (BNC)
03-33-8424	4-channel DAC
03-33-8440	Dual input CAN-bus/GPS card

DATS™ Professional software (01-55-622)

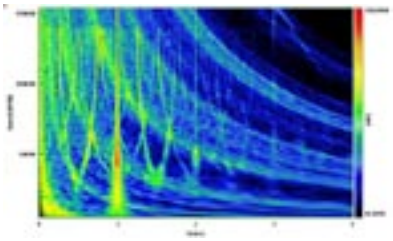
- **Acquisition, analysis & reporting**
- **Wide range of analysis functions**
- **Automated processing through DATS Scripts**
- **Built-in Report Generator (Intaglio)**
- **Comprehensive QA features**



The DATS Professional software package contains all of the essential parts of the DATS software. It includes the data acquisition software for controlling the Prosig P5000/P8000 hardware and capturing data. The Professional package also provides all of the DATS analysis frameworks such as worksheets and scripting language. The Intaglio report generation facility is also included in the package.

DATS Professional Software	
01-55-622	DATS Professional software. Includes Intaglio reporting suite, Macro & Script support and P5000/P8000 acquisition software.

DATS™ Rotating Machinery Analysis Suite (01-55-802)



- **Waterfalls & order tracking**
- **Time sampled & angle sampled data**
- **Special analysis for angle sampled data**

The DATS Rotating Machinery option contains a complete set of tools for analyzing the sources of vibration and noise caused by cyclic forces such as those found in engines, gearboxes and wheel excitation. The software is designed to work with data sampled in both the time and angular domains.

DATS Rotating Machinery Analysis Suite	
01-55-802	Rotating Machinery analysis suite (Requires 01-55-622 DATS Professional)

Visit **http://www.prosig.com/** for more details or to request a full catalogue. Or email your queries to **sales@prosig.com**.