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IMPROVEMENT OF SIGNAL TO NOISE IN FREQUENCY SPECTRUM MEASUREMENTS

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Noise on frequency spectra of operating data may, in many cases be of an unknown level and source. For good analysis this should not be the case. A vibration spectrum of a running machine, for example, should contain a clear picture of machine dynamics and not be distorted by instrumentation noise or background hash. If this is not the case, the analysist should know why.

Background and instrument noise can be measured. For example, it is good practice to use a dummy channel to continually monitor system noise. Dynamic range must be known, there is little value in measuring combustion chamber pressure over a 80 dB dynamic range and recording the information on an FM tape recorder with 35-45 dB dynamic range, for example. Frequency limitations should also be known. All systems have a resonant frequency and many do not operate down to DC. There is no point in using a large accelerometer to measure frequencies at 5 kHz when it has a resonance of 6 kHz. Good practice says 1.5 kHz is the maximum.

Often though, one has to live with noise, poor signal to noise ratio or just low level signals. Offending devices like slip rings and radio links or environments such as water, heavy traffic vibration or other machinery noise are common causes of unavoidable noise. The problem is to extract the signal from the noise.

SIGNAL AVERAGING

LINEAR

The most straight forward method is to add successive spectra in such a way that each contributes an equal portion of the total. This method is called linear, or ensemble averaging and generally follows the form:

$$A_i = 1/M \left(S_{(j-1)} + X_j\right)$$

$$\text{where } M = 2^m \text{ such that } 2^{m-1} < j \leq 2^m$$

Using this method coherent continuous signals will remain at constant level whereas any random or non-continuous signals will decrease in amplitude. In general the larger the number of averages, the better the result. The limitations are that the data must be stationary over the averaging period for an accurate result, and there must be sufficient data to product enough averages for S/N improvement.

EXPONENTIAL AVERAGING

The exponential average has the effect of producing a spectrum that varies with time with a good attack rate and exponential decay such that:-

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$$A_i = 1/M \left(\frac{N-1}{N} \; S_{(i-1)} + X_i\right)$$

$$\text{where } i = N + 1, N + 2, N + 3 \ldots$$

A time constant of N averages is apparent when exponential averaging is done.

The advantages of this technique are that rapidly varying data will be observed as will short duration transients. Signal to noise will be improved in proportion to the value of N.

SYNCRONOUS AVERAGING

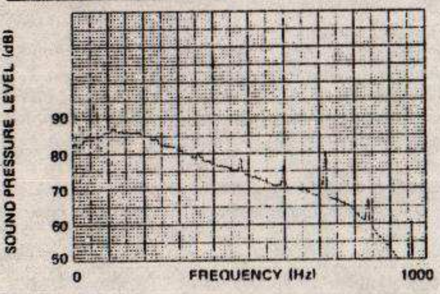


Figure 1A Total Sound Pressure Level Spectrum

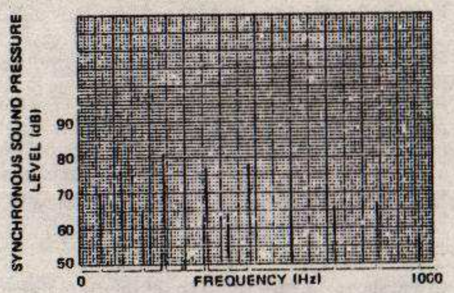


Figure 1B Synchronous Sound Pressure Level Spectrum

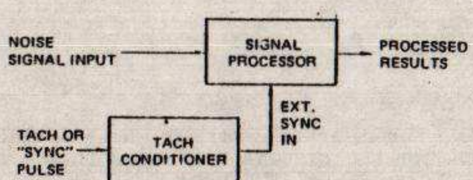
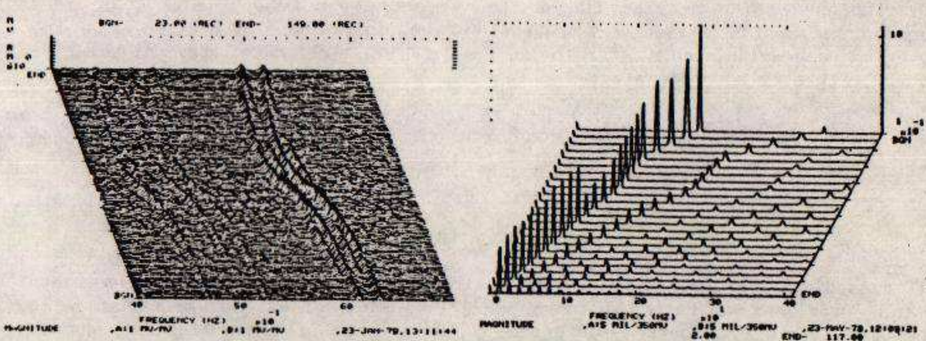


Figure 2. Concept for Measuring Synchronous Power Spectra

In complex rotating machinery analysis, it can help if the spectra is syncronised to a tachometer signal. The spectra are then triggered at the same point for each ensemble. All non rotating components of the spectrum will be 'averaged out' leaving only the syncronous signal. If the tachometer signal is divided or multiplied, then other syncronous parts such as gears and blades may be examined while the non-syncronous signals are attenuated.

VISUAL INTERPOLATION

If one spectra is displayed without averaging and the signal to noise is less than 1 ÷ 1, then the signal will not be identifiable. When averaging occurs, the noise level is reduced because of its randomness, but the measured signal must be stationary. If the signal is non-stationary, or a transient of low level and syncronisation is impossible, then the waterfall technique remains. Spectra are run down the page close together so that any continuities line up visually, it is possible to distinguish signals well below the noise floor.



An acoustic analysis plot produced by a Spectral Dynamics Modal System showing the Doppler shift within a signal from a moving source. (Time: bottom to top)

Fig. 3

A vibration plot from a rotating machine, clearly showing variations in the amplitude of the fundamental and various harmonic orders as it coasts to a stop. (Time: top to bottom)

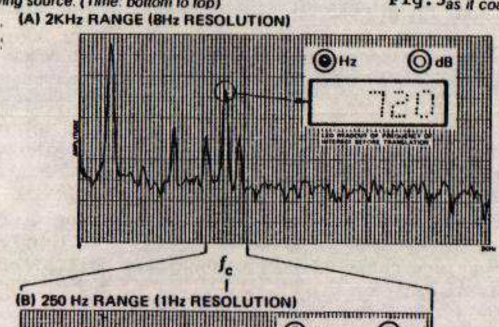


Fig. 4

BANDWIDTH REDUCTION

For random signals the power spectral density is given by the following:

$$PSD = \frac{\text{Mean Signal}}{BW} = \frac{(RMS)^2}{BW}$$

If the noise level is constant, that is a constant total RMS over the whole spectrum, then the level in a particular spectral cell or line will depend on its bandwidth. A 10 times increase in resolution gives a 3dB reduction in noise. Any sinusoidal components will be unaffected, thus an improvement of 3dB in signal to noise of the measurement has occured.

Thus optimun use of base band and frequency translation or zoom to give maximum resolution will give maximum signal to noise, but analysis duration will be extended.

OVERLAP PROCESSING

The FFT technique requires that a weighting function be applied to the time domain before conversion to the frequency domain. As a result there is considerable data loss. If only one spectrum is generated per memory period, there is a discontinuity of analyses due to the weighting function.

Overlap processing enables two or four spectra per memory period, or more commonly a constant maximum FFT conversion rate. In the case of a fixed FFT rate, overlap processing occurs up to the analysers 'real time' rate. Several benefits occur with overlap processing:-

1. There is no data loss
2. Averaging is faster
3. Visual resolution is improved as the display is more stable
4. Waterfall displays show more due to higher density of spectra

SUBTRACTION OF NOISE

If a machine is being run in a noisy environment, before and after measurements may be made then subtracted to leave just the machine noise. This method may also be used to correct spectra distorted by instruments with non linear frequency responses. Most modern spectrum analysers have this capability.

TWO CHANNEL TECHNIQUES

The cross spectrum and coherent output power spectrum both give outputs that may be more valuable than the original two spectra. For example, the noise emitted by a machine may be distorted due to the noise from other machines. In that case an accelerometer on the machine will give a reference for coherence of the noise signal. Then the product of the coherence function and noise spectrum will give a measure of coherent output power from that machine.

All these techniques are possible with the modern FFT analyser whether single or two channel. Most analysers can be interfaced with computers for automatic analysis. Peripherals such as the signature ratio adaptor, tachometer multiplier and waterfall are also readily available.