VIBRATION ANALYSIS GLOSSARY

Accelerometer

A transducer whose output is electrical / mechanical directly proportional to acceleration forces. The output is usually produced by force applied to a piezoelectric crystal which generates a current proportional to the applied force. This current is then amplified and displayed as a time waveform or processed by a Fourier transform to produce a frequency display. Single integration of the acceleration signal will produce a velocity display and double integration of the acceleration signal will produce a displacement display.

Accuracy

How close a measurement is to the absolute quantity.

Acoustic Emission

The detected energy that is generated when materials are deformed or break. For rolling element bearing analysis, it is the periodic energy generated by the over rolling of particles or flaws and detected by the display of the bearing flaw frequencies.

Algorithm

A specific procedure for solving mathematical problems. An FFT is an algorithm.

Alignment

A condition whereby the axes of machine components are either coincident, parallel or perpendicular, according to design requirements, during operation.

Amplitude

The measurement of energy or movement in a vibrating object. Amplitude is measured and expressed in three ways: Displacement (commonly in mils Pk-Pk); Velocity (commonly in In/Sec Pk); and Acceleration (commonly in Gs RMS). Amplitude is also the y-axis of the vibration time waveform and spectrum, it helps define the severity of the vibration.

Analog

Quantities in two separate physical systems having consistently similar relationships to each other are called analogous. One is then called the analog of the other. The electrical output of a transducer is an analog of the vibration input of the transducer as long as the transducer is not operated in the nonlinear (overloaded) range. This is in contrast to a digital representation of the vibration signal, which is a sampled and quantisized signal consisting of a series of numbers, usually in binary notation.

Analog to Digital Conversion

The process of sampling an analog signal produces a series of numbers which is the digital representation of the same signal. The sampling frequency must be at least twice as high as the highest frequency present in the signal to prevent aliasing errors.

Angularity

The angle between two shaft center lines; this angle is the same at any point along either centerline. It is normally specified in rise/run.

Asynchronous
Nonsynchronous

Frequencies in a vibration spectrum that exceed shaft turning speed (TS), but are not integer or harmonic multiples of TS, also commonly referred to as non-synchronous.

Averaging

In performing spectrum analysis, regardless of how it is done, some form of time averaging must be done to accurately determine the level of the signal at each frequency. In vibration analysis, the most important type of averaging employed is linear spectrum averaging, where a series of individual spectra are added together and the sum is divided by the number of spectra.

Averaging is very important when performing spectrum analysis of any signal that changes with time, and this is usually the case with vibration signals of machinery. Linear averaging smoothes out the spectrum of the random noise in a spectrum making the discrete frequency components easier to see, but it does not actually reduce the noise level.

Another type of averaging that is important in machinery monitoring is time domain averaging, or time synchronous averaging, and it requires a tachometer connected to the trigger input of the analyzer to synchronize each "snapshot" of the signal to the running speed of the machine. Time domain averaging is very useful in reducing the random noise components in a spectrum, or in reducing the effect of other interfering signals such as components from another nearby machine.

See also Time Synchronous Averaging.

Axial

In the same direction as the shaft centerline.

Axial Float (or End Float)

Movement of one shaft along its centerline due to the freedom of movement permitted by a journal bearing or a sleeve bearing. This adjustment should be set before performing vertical or horizontal moves. The degree of axial float can be adjusted by the position of the stops, or whatever limits the motion.

Backlash

A condition where a rotor can rotate freely for a certain angular distance before encountering any resisting force. It may be measured in degrees. This term normally applies to couplings and gears.

Bearing

Primarily two types, rolling element and sleeve or plain bearing. Rolling element bearings consist of four parts: an inner race, an outer race, balls or rollers, and a cage to maintain the proper separation of the rolling elements. A sleeve bearing is a cylinder of alloy metal surrounding the rotating shaft. Contact between the shaft and sleeve is prevented by a lubrication film.

Bearing Frequencies

Faults in any of the four bearing components will generate specific frequencies dependent upon the bearing geometry and rotating speed.

BPFO - Ball Pass Frequency, Outer Race
BPFI - Ball Pass Frequency, Inner Race
BSF - Ball Spin Frequency
FTF - Fundamental Train Frequency

Bearing Misalignment

A misalignment that results when the bearings supporting a shaft are not aligned with each other. The bearings may not be mounted in parallel planes, cocked relative to the shaft, or distorted due to foundation settling or thermal growth.

Beat Frequency

If two vibration components are quite close together in frequency and if they are present at the same time at the same place, they will combine in such a way that their sum will vary in level up and down at a rate equal to the difference in frequency between the two components. This phenomenon is known as beating, and its frequency is the beat frequency.

There is confusion in some areas between beating and amplitude modulation, which also can produce an undulating vibration level. Amplitude modulation is different from beating, and is caused by a high-frequency component being multiplied by a lower-frequency component and is thus a nonlinear effect, whereas beating is simply a linear addition of two components whose frequencies are close to one another.

Bow

A shaft condition such that the geometric centerline of the shaft is not straight.

Bump Testing

A single channel approximation to a two channel impact test. This method works because the impacting force approximates an impulse and imparts broadband excitation over a limited frequency range. Since the Fourier Transform of the impulse response function is the frequency response function, it provides a good method of estimating the natural frequencies of the structure.

Damping

Energy dissipation in an oscillating structure. For free vibration, that results in a decay in the amplitude of motion over time.

Detector

An electronic circuit that determines the amplitude level of a signal in accordance with certain rules. The simplest type of detector consists of a resistor and a capacitor, and it measures the average value of a fluctuating DC signal. A more complex but much more useful type of detector is an RMS detector. RMS detectors are used because they are proportional to the power or energy present in the signal or a vibration.

Digital

Digital instrumentation consists of devices that convert analog signals into a series of numbers through a sampling process and an analog to digital converter. They then perform operations on the numbers to achieve such effects as equalization, data storage, data compression, frequency analysis, etc. This process in general is called digital signal processing. It is characterized by several advantages and disadvantages. One advantage is that the converted signals can be manipulated, transformed and copied without introducing any added noise or distortion. The disadvantage is that the signal representation may not be truly representative of the original signal.

Discrete

With reference to a spectrum, discrete means consisting of separate distinct points, rather than continuous. An example of a discrete spectrum is a harmonic series. An FFT spectrum, which consists of information only at specific frequencies (the FFT lines), is actually discrete regardless of the input signal. For instance, the true spectrum of a transient is continuous, and the FFT of a transient appears continuous on the screen, but still only contains information at the frequencies of the FFT lines.

The input signal to an FFT analyzer is continuous, but the sampling process necessary to implement the FFT algorithm converts it into a discrete form, with information only at the specific sampled times.

Discrete Fourier Transform

The mathematical calculation that converts, or "transforms" a sampled and digitized waveform into a sampled spectrum. The fast Fourier transform, or FFT, is an algorithm that allows a computer to calculate the discrete Fourier transform very quickly. See also Fast Fourier Transform.

Dynamic Stiffness

The frequency response function of force/displacement.

Eddy current probe

A non-contact electrical device that measures the displacement of one surface relative to the tip of the probe. Construction consists of an electrical coil of various lengths and diameters. This coil located in the tip of the probe is energized producing an electrical field around the tip of the probe. When a conductive surface is placed in the field and the distance from the probe is noted, variations in this gap can be determined by the variations in the voltage flow to the probe tip.

End Float

See axial float.

Engineering Units, EU

The units in which a measurement is made; for instance velocity may be expressed in millimeters per second, miles per hour, or furlongs per fortnight, depending on the use to which the data will be put. Modern instrumentation, such as FFT analyzers allow one to specify what the engineering units are and to apply conversion factors if needed.

EU

See Engineering Units.

Fast Fourier Transform (FFT)

The FFT is an algorithm, or digital calculation routine, that efficiently calculates the discrete Fourier transform from the sampled time waveform. In other words it converts, or "transforms" a signal from the time domain into the frequency domain. See also DFT.

The illustration shows the relation between the time record length, the time between samples, the frequency span f and the frequency resolution. The most important relation here is that the frequency resolution is inversely proportional to time record length. Therefore, high-resolution spectrum analysis of necessity takes a long time to collect the time record.

FFT

See Fast Fourier Transform.

FFT Analyzer

The FFT analyzer is a device that uses the FFT algorithm to calculate a spectrum from a time domain signal, and is the most common type of spectrum analyzer available today. The FFT analyzer is a very useful device, and is available in a great variety of models with varying complexity. It is the heart of any machinery predictive maintenance program. See also Fast Fourier Transform.

Filter

A filter is an electrical circuit that allows signals in certain frequency ranges to pass through, and attenuates or blocks all other frequencies. There are many types of filters, such as low pass filters, high pass filters, and band pass filters. Examples of filters used in

machinery monitoring instruments are low pass filters to reject high frequency noise and to prevent aliasing, and high pass filters to reject low frequency noise. Variable frequency band pass filters were used in the past to perform spectrum analysis, but they have been largely supplanted by the FFT analyzer.

Frequency

The repetition rate of a periodic vibration, per unit of time, determined by taking the reciprocal of the period (T). Frequency is expressed in three ways: Hz (how many cycles per second); cpm (how many cycles per minute); and orders (how many cycles per shaft turning speed [TS]). Frequency is also the x-axis of the vibration spectrum; it identifies the source of the vibration.

Frequency

Frequency is the reciprocal of time. If an event is periodic in time, i.e. if it repeats at a fixed time interval, then its frequency is one divided by the time interval. If a vibrating element takes one tenth of a second to complete one cycle and return to its starting point, then its frequency is defined to be 10 cycles per second, or 10 hertz (Hz). Although the SI standard unit of frequency is the Hz, when analyzing machinery vibration it is sometimes more convenient to express frequency in cycles per minute (cpm), which corresponds to rpm. Frequency in cpm is simply frequency in Hz times 60. Another common frequency representation used in machinery monitoring is multiples of turning speed, or "orders." Frequency in orders is frequency in cpm divided by the turning speed of the machine. The second order is then the second harmonic of turning speed, etc. This is especially convenient if the machine is varying in speed, for the frequency representation on a spectrum will be the same regardless of speed. Two spectra from the same machine can therefore more easily be compared if they are both expressed in orders. Conversion of the frequency axis of a spectrum to orders is called "order normalization," and is done by vibration monitoring analyzers.

Frequency Response

The frequency response function, also called the FRF, is a characteristic of a system which has a measured response resulting from a known applied input. In the case of a mechanical structure, the frequency response is the spectrum of the vibration of the structure divided by the spectrum of the input force to the system. To measure the frequency response of a mechanical system, one must measure the spectra of both the input force to the system and the vibration response, and this is most easily done with a dual-channel FFT analyzer. Frequency response measurements are used extensively in modal analysis of mechanical systems.

The frequency response function is actually a three-dimensional quantity, consisting of amplitude vs. phase vs. frequency. Therefore a true plot of it requires three dimensions, and this is difficult to represent on paper. One way to do it is the so-called Bode plot, which consists of two curves, one of amplitude vs. frequency and one of phase vs. frequency. Another way to look at the frequency response function is to resolve the phase portion into two orthogonal components, one in-phase part (called the real part), and one part 90

degrees out of phase (called the "quadrature" or "imaginary" part). Sometimes these two phase parts are plotted against each other, and the result is the so-called Nyquist plot.

<u>Fundamental Frequency</u>

1. **The spectrum of a periodic signal will consist of a fundamental component at the reciprocal of the period and possibly a series of harmonics of this frequency. The frequency is directly related to the phase-locked, rotational speed being measured and its amplitude may be low enough that it is difficult to see in the spectrum.**

2. **The spectrum of a periodic signal will consist of a fundamental component at the reciprocal of its period and a series of harmonics of this frequency. The fundamental is also called the "first harmonic." It is possible to have a periodic signal where the fundamental is so low in level that it cannot be seen, but the harmonics will still be spaced apart by the fundamental frequency.**

<u>Harmonic</u>

A frequency that is an integer multiple of a given (subsynchronous, synchronous or nonsynchronous) frequency.

<u>Harmonics</u>

Harmonics, also called a harmonic series, are components of a spectrum which are integral multiples of the fundamental frequency. A harmonic series in a spectrum is the result of a periodic signal in the waveform. Harmonic series are very common in spectra of machinery vibration.

<u>Hertz</u>

The unit of frequency in the SI measurement system is the hertz, abbreviated Hz. One hertz is equal to one cycle per second. The name is in honor of Heinrich Hertz, an early German investigator of radio wave transmission.

<u>High-Pass Filter</u>

A filter that passes signal frequencies above a specific, or cut off, frequency is called a high pass filter. They are used in instrumentation to eliminate low-frequency noise, and to separate alternating components from direct (DC) components in a signal.

<u>Hysteresis</u>

Non-uniqueness in the relationship between two variables as a parameter increases or decreases. Also called deadband, or the portion of the system's response where a change in input does not produce a change in output.

<u>Impact Testing</u>

A method of measuring the frequency response function of a structure by hitting it with a calibrated hammer and measuring the system's response. The impact hammer is instumented with a load cell to measure the input force pulse while the response is typically

measured using an accelerometer. The impact imparts a force pulse to the structure which excites it over a broad frequency range.

Jack Shaft

A long shaft that is used as a spacer between two machines. Also, a long turning shaft with several sheaves.

Level

In common usage the level of a signal is its amplitude, but strictly speaking the term should be reserved for the amplitude expressed on a decibel scale relative to a reference value.

Low Pass Filter

A filter that passes signals with less than 3 dB attenuation up to its cutoff frequency, and attenuates the signal above that frequency. The attenuation slope is called the roll off, q.v. An anti-aliasing filter is an example of a low pass filter.

Mils

A unit of measure for displacement (thousandths of an inch). Usually measured in mils peak to peak, which represents total displacement.

Mils/Inch

A unit (normally English) used to describe the angle of one shaft centerline to the other. It is equivalent to milliradians. It can also be expressed as rise/run (1 unit = 17.45 mils/inch), as long as the rise is measured in mils and the run is measured in inches.

Natural Frequency

The frequency of oscillation of the free vibration of a system if no damping were present.

Noise

Any unwanted signal. Can be random or periodic.

Nonsynchronous
Asynchronous

Frequencies in a vibration spectrum that exceed shaft turning speed (TS), but are not integer or harmonic multiples of TS. See asynchronous.

Peak

The maximum positive or negative dynamic excursion from zero (for an AC coupled signal) or from the offset level (for a DC coupled) of any time waveform. Sometimes referred to as "true peak" or "waveform peak."

Peak-to-peak

The amplitude difference between the most positive and most negative value in the time waveform.

<u>Period</u>

A signal that repeats the same pattern over time is called periodic, and the period is defined as the length of time encompassed by one cycle, or repetition. The period of a periodic waveform is the inverse of its fundamental frequency.

<u>Periodic</u>

A signal is periodic if it repeats the same pattern over time. The spectrum of a periodic signal always contains a series of harmonics.

<u>Perpendicular</u>

At right angles (90°) to a given line or plane.

<u>Phase (time lag or lead)</u>

The difference in time between two events such as the zero crossing of two waveforms, or the time between a reference and the peak of a waveform. The phase is expressed in degrees as the time between two events divided by the period (also a time), times 360 degrees.

<u>Pipe Strain</u>

Casing and flange distortion caused by improper pipe flange fit up.

<u>Radial</u>

Direction perpendicular to the shaft centerline.

<u>Radial Position</u>

The average location, relative to the radial bearing centerline, of the shaft's dynamic motion. Applies only to sleeve bearings.

<u>Repeatability</u>

The consistency (or variation) of readings and results between consecutive sets of measurements. It has nothing to do with accuracy.

<u>Resolution</u>

The smallest change or amount a measurement system can detect.

<u>Resonance</u>

When a forcing frequency is the same as a resonant frequency of the structure, the structure is said to be in resonance.

Resonant Frequency

The frequency of maximum amplification for a given damping ratio, . Resonant frequency

Sensor

Any device that translates the magnitude of one quantity into another quantity. Three of the most common transducers used in vibration measurements are accelerometer, velocity transducer, and eddy current probe.

Shim

A thin piece of material inserted between the machine feet and the baseplate used to produce precise vertical adjustments to the machine centerline. Shims are normally made of stainless steel, mild steel, or plastic. Shims come in various thicknesses from 1 mil to 125 mils.

Sidebands

Sidebands are spectral components that are the result of amplitude or frequency modulation. The frequency spacing of the sidebands is equal to the modulating frequency, and this fact is used in diagnosing machine problems by examining sideband families in the vibration spectrum. For instance, a defective gear will exhibit sidebands spaced apart at the gear rpm around the gear mesh frequency.

Signal

In vibration analysis, a signal is an electric voltage or current which is analog of the vibration being measured.

Soft Foot

A term used to describe any condition where tightening or loosening the bolt(s) of the machine feet distorts the machine frame.

Spectra

Spectra is the plural of spectrum.

Spectrum

The spectrum is the result of transforming a time domain signal to the frequency domain. It is the decomposition of a time signal into a collection of sine waves. The plural of spectrum is spectra. Spectrum analysis is the procedure of doing the transformation, and it is most commonly done with an FFT analyzer.

Spectrum Analyzer

A spectrum analyzer converts a signal from the time domain into the frequency domain, and the FFT analyzer is the most common type today, but there are many other types.

Stationary Signal

A stationary signal is a signal whose average statistical properties over a time interval of interest are constant, and it may be deterministic or not. In general, the vibration signatures of rotating machines are stationary.

Structural Modification

Mathematically determining the effect of changing the mass, stiffness, or damping of a structure and determining its new modal parameters. A modal analysis provides, in essence, a mathematical model of the structure. This model can be manipulated to determine the effect of modifications to the structure. The modal model can be generated either experimentally or using a finite element program.

Sub Harmonic

Sub harmonics are synchronous components in a spectrum that are multiples of 1/2, 1/3, or 1/4 of the frequency of the primary fundamental. They are sometimes called "sub-synchronous" components. In the vibration spectrum of a rotating machine, there will normally be a component at the turning speed along with several harmonics of turning speed. If there is sufficient looseness in the machine so that some parts are rattling, the spectrum will usually contain sub harmonics. Harmonics of one-half turning speed are called "one-half order sub harmonics," etc.

Subsynchronous

Frequencies in a vibration spectrum that are lower than the fundamental frequency.

Sub synchronous

See Sub Harmonic.

Synchronous

Synchronous literally means "at the same time," but in spectrum analysis, synchronous components are defined as spectral components that are integral multiples, or harmonics, of a fundamental frequency. They may in some cases exist as multiples of an integral fraction of the fundamental frequency, in which case they are called sub harmonics.

Thermal Growth

Movement of the shaft center lines associated with (or due to) a change in machinery temperature between the static and operating conditions.

Thermal Profile

A secondary alignment method used to measure thermal growth. This method is only used for calculating the vertical thermal growth of the shaft centerline due to a change in temperature. The shim plane, under the machine feet, serves as a benchmark. This technique is usually used for machines under 500 HP. The technique uses the linear expansion equation where: Expansion in mils (E) is equal to the average change in

temperature, F° (T) multiplied by the vertical distance from the shim plane to the shaft centerline, in inches mutiplied by the coefficient of thermal expansion, in mils/inch F°. E =3D T X L X C This is to be calculated for both sides of the bearing. The number of temperature readings is not critical, but at least 4 is recommended. The average change in temperature is between the offline and online temperatures.

TIR

Total Indicator Runout. The total movement in mils of a dial indicator after a given rotation of a rotor.

Tolerance

The maximum permissible deviation from the specified quantity.

Transducer

Any device that translates the magnitude of one quantity into another quantity. Three of the most common transducers used in vibration measurements are accelerometer, velocity transducer, and eddy current probe.

Velocity Transducer

An electrical/mechanical transducer whose output is directly proportional to the velocity of the measured unit. A velocity transducer consists of a magnet suspended on a coil, surrounded by a conductive coil. Movement of the transducer induces movement in the suspended magnet. This movement inside the conductive coil generates an electrical current proportional to the velocity of the movement. A time waveform or a Fourier transform of the current will result in a velocity measurement. The signal can also be integrated to produce a displacement measurement.

Waveform

The waveform is the shape of a time domain signal as seen on an oscilloscope screen. It is a visual representation or graph of the instantaneous value of the signal plotted against time. Inspection of the waveform can sometimes reveal information about the signal that the spectrum of the signal does not show. For instance a sharp spike or impulse and a randomly varying continuous signal can have spectra that look almost identical, while their waveforms are completely different. In machine vibration, spikes are usually caused by mechanical impacting, while random noise can be caused by the advanced stages of bearing degradation.