The Time Waveform

Stuart Courtney
Field Service Manager (Europe)
Entek IRD International Incorporated

Introduction

The Time Waveform is the complex sum of all the individual frequencies that exist on a machine. That statement in itself is cause for confusion and not very helpful to the vibration analyst.

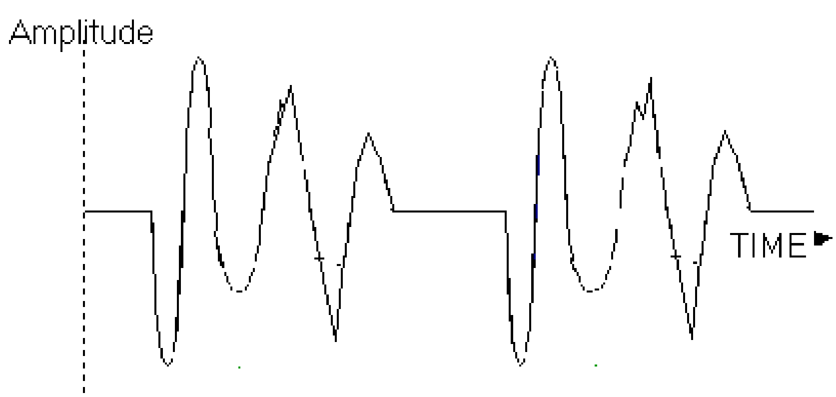
In order to correctly analyse the Time Waveform we must first understand what it is and then decide whether it will be of use to us when trying to analyse problems in our machines and systems.

We must understand that there are certain faults that can only be seen in the Time Waveform and lack of use of the TWF measurement will mean we may miss the development of a fault. We must then learn to interpret the waveform in the simplest possible way.

The aim should always be to detect change in machinery condition at the earliest opportunity using the simplest method possible.

What is the Time Waveform?

The most basic description of the Time Waveform is that it is the raw unprocessed signal that we get from the vibration sensor when we display it on an oscilloscope. This would normally be in an analogue format and would typically appear as shown below.



As the development of portable data collectors progresses, the opportunity to collect digitised Time Waveform data is enhanced and made more user friendly. The challenge is to use the power of these systems to enhance machine condition monitoring systems. There is also the requirement to ensure that we do not collect Mbytes of useless data.

Digital systems up to now have only replicated the same information in a format that can be easily collected and stored.

There are many machine faults that can only be detected using the Time Waveform and these faults and the correct set-up will be discussed later in this paper.

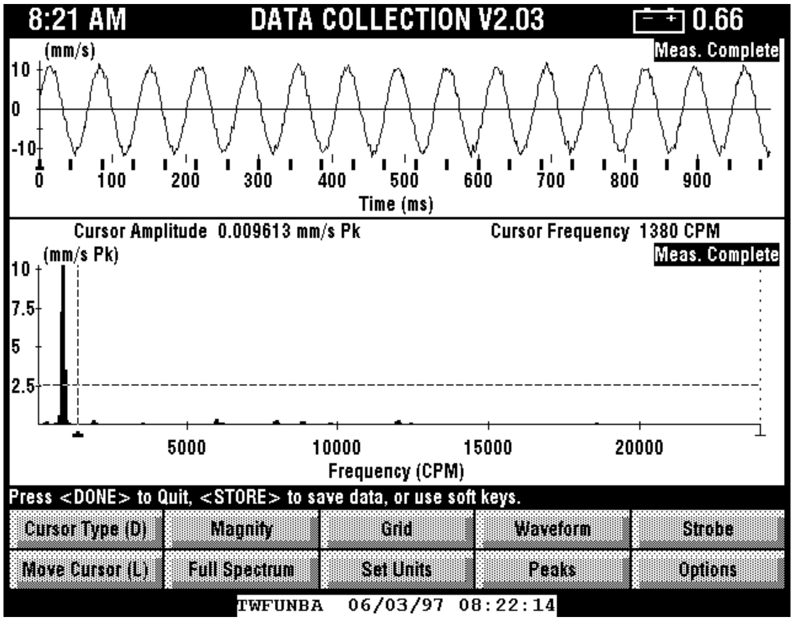
Why use the Time Waveform

As maintenance engineers we find the time domain to be alien to us, if asked what speed a machine runs at we normally reply with 1500 rpm or some integer determined by the process. We sometimes reply with 25 Hz but rarely would we say 40 milliseconds per rev. We could therefor wonder why we need to use this method of measurement and why should we even consider becoming involved in it's confusing set-up and use.

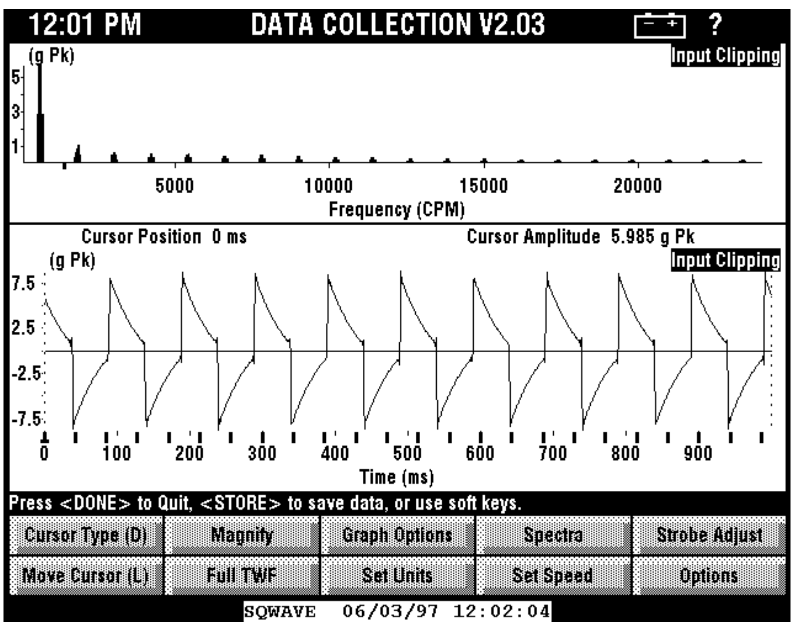
There are perfectly good reasons why we should selectively use the Time Waveform these will be discussed later in this paper.

Example spectrum.

Take for example the case of a 1 x RPM vibration that occurs due to imbalance, this will display the following spectrum and Time Waveform. The signal will be sinusoidal in it's format and will give a very pronounced 1 X peak in the Fast Fourier Transform display. The time waveform also shows that there are some low amplitude, high frequency vibration that is not readily available in the spectrum display. From the time waveform there can be little doubt that the problem is unbalance but the spectrum would need more analysis before confirming this conclusion.



The spectrum and waveform below are an example how there could be a similar spectrum to unbalance but the problem is an impactive form of vibration signal, time waveform shows that you can easily be misled by the spectrum data



Problems detectable by the Time Waveform and possibly missed by spectral analysis

a. Cracked, Broken or Deformed Gear Teeth

b. Rolling Element Bearing Defects on Very Low Speed Machines (<10 RPM)

c. Motor Startup Transient Problems that cause Bearing Deterioration & Winding Problems

d. Reciprocating Compressors: Short-lived Impact Type Vibration by Problems with Piston Slap, Loose Rod & Main Bearings, and Inlet/ Discharge Valves

Problems for which the Time Waveform helps to confirm spectral analysis suspicions.

a. Low to Moderate Speed Machine (60-200 RPM) Rolling Element Bearing Defects.

b. Motor Electrical Problems including Stator, Air Gap & Rotor Defects.

c. Proximity Probe diagnosis of target area faults.

d. Rotor Rubs.

e. Chatter in cutting operations in machine tools.

f. Distinguishing Between Misalignment and Looseness Problems.

g. Reciprocating machinery - Misfiring, Combustion Problems.

Some other points need to be made about Time Waveforms as a reminder to the analyst who may not have considered these for some time:

a. A spectrum of amplitude versus frequency does not provide complete information about a signal even for a single, steady-state sine wave because it does not include phase. Furthermore, even less information may be available for more complex vibration signals.

b. Time Waveforms are a powerful method for studying the vibration characteristics of electric motors, particularly during the event just before its power is terminated, just as it is cut off, and then the response immediately after loss of power as the motor coasts to a stop.

c. Unlike a static representation of a spectrum, a still picture of a Time Waveform can display pulsating amplitudes (beats or modulations) as well as changes in frequencies themselves.

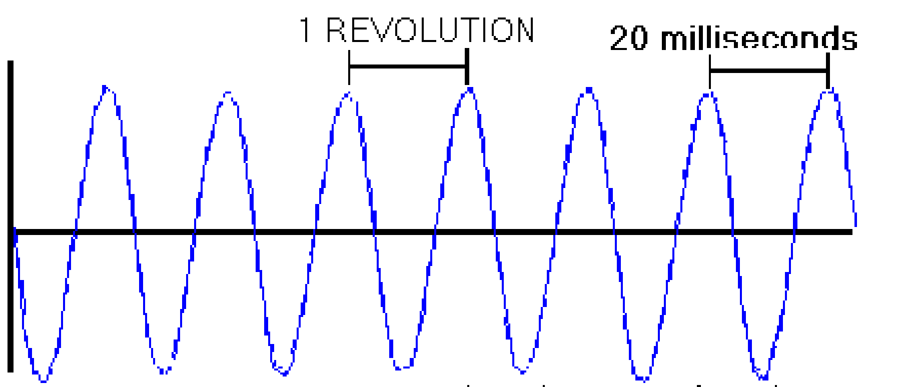
d. A Time Waveform displays the true overall peak amplitude whereas that of the FFT is only computed from an RMS spectrum ("peak amplitude" = 1.414 X RMS). An FFT can actually fail to display the amplitudes of important impact events. In reality, the true peak response is likely to be far different from this, particularly for such examples as bearing and gear problems. The use of the Time Waveform is becoming increasingly popular as a method of confirming bearing and gear problems.

e. Time Waveforms can display phase relationships between different frequencies and, if comparing waveforms in a dual channel analyzer, can directly determine the phase between data taken at each of two locations.

f. Time Waveforms give a measure of damping within the system, particularly for a waveform captured during an impulse natural frequency test (bump test).

Effective set-up for Time Waveform analysis.

Before we can analyze the Time Waveform it may be helpful to understand the measurement parameter set-up for the collected data.



The waveform above represents a vibration due to a pure imbalance situation, this is a very unlikely event and has only been produced to help with the interpretation of the waveform.

The example above is the Time Waveform of a machine running at 1500 RPM, in order to acquire the above the data collector or analyzer has been setup to obtain a total length of data of 140 milliseconds. This represents 7 total revolutions of the shaft. The waveform setup will also require that the number of data sets be entered to ensure that the resolution of the acquired data is sufficient to extract the relevant information from the measured signal. At this point we start to see the relationship of the waveform to the spectrum and the spectrum parameters, the number of data sets is directly proportional to the number of spectral lines. The relationship is determined by the anti aliasing filter that the analyzer uses. Most data collectors use the same format of filter in that the maximum frequency that is acquired is 2.56 times the maximum frequency to be measured. This gives a relationship of the following:- 1024 data sets divided by 2.56 equals 400 lines of resolution in the spectrum. The following table will help with the set-up of the Time Waveform.

THE TIME WAVEFORM SETUP.

Period (True) uSec	Total Period mSec	Freq. 1/Tot Per Hz	Fmax Kcpm
15.63	16.3	62.50	1500
19.53	20.4	50.00	1200
21.70	22.5	45.00	1080
30.04	31.7	32.50	780
39.06	40.9	25.00	600
43.40	45	22.50	540
48.83	51.2	20.00	480
55.80	58.3	17.50	420
65.10	68.6	15.00	360
78.13	81.9	12.50	300
97.66	102.4	10.00	240
130.20	136.1	7.50	180
195.30	204.8	5.00	120
390.60	409.6	2.50	60
434.00	454.6	2.25	54
488.30	512.0	2.00	48
558.00	584.7	1.75	42
651.00	683.0	1.50	36
781.30	819.2	1.25	30
976.60	1024.0	1.00	24
1302.00	1364	0.75	18
1953.00	2048	0.50	12
3906.00	4096	0.25	6
7813.00	8192	0.125	3
15625.00	16384	0.0625	1.5

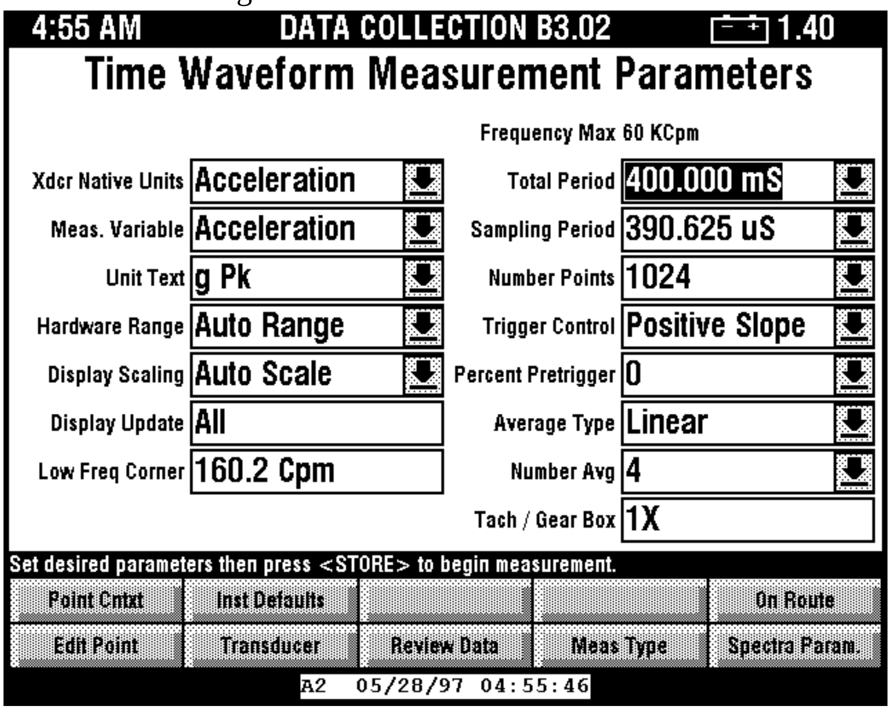
The total period shown in the above table is that shown on the data collector setup screen, the frequency shown is the correct frequency for the first column of the period. The **frequency** indicates the lowest frequency that can be resolved.

For a 400 line FFT spectrum (1024 data size) the following formula can be used.
To calculate the number of lines of FFT, divide the data size by 2.56 (anti alias filter constant) e.g. 1024/2.56 = 400

The Fmax in CPM can be calculated by using the following formula: fmax = (1/period x 1024) x 60 x 400

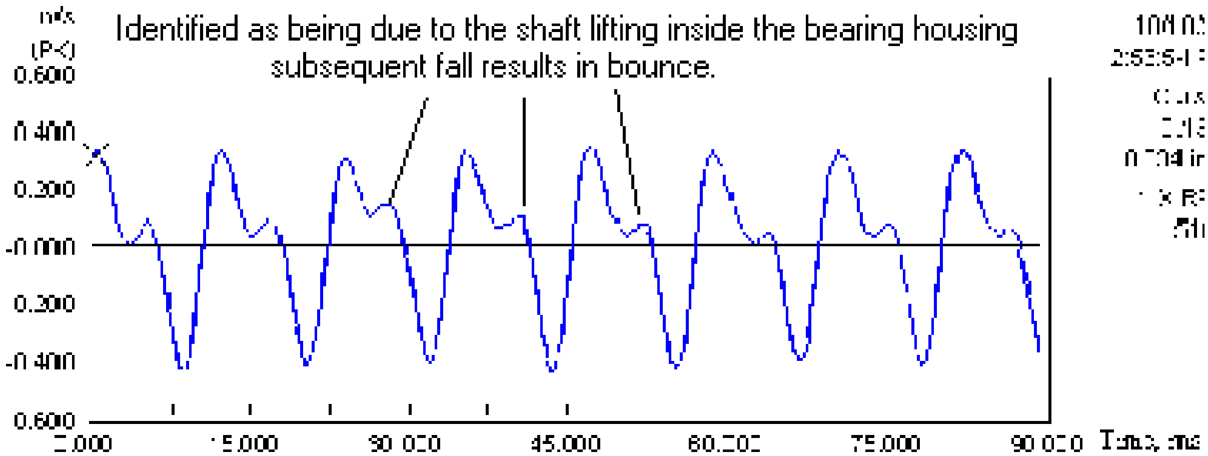
Modern data collector systems can considerably help the vibration analyst to set-up the Time Waveform parameters, the setup screen below is taken from the Entek IRD dataPAC 1500 advanced data collector.

The example set-up from the dataPAC 1500 shows how an advanced data collector can assist with the set-up of the Time Waveform. For the total period of 400 MSeconds the resultant FMax is displayed above the input box as 60 KCPM, this changes dynamically as the mixture of settings is adjusted to suit the particular problem being analysed. For example if the total period stayed the same and the number of points was changed to 2048 the FMax would change to 120 KCPM.



Analysis of some Time Waveform examples.

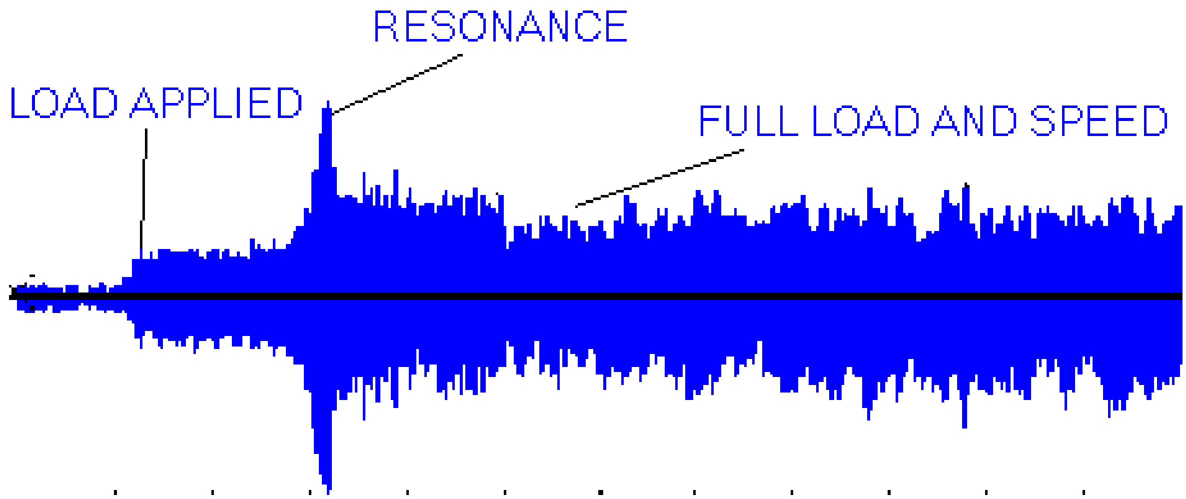
The example below shows the waveform taken from a bearing housing, the condition of looseness is sometimes difficult to confirm just from the spectrum and can easily be misinterpreted as misalignment. The use of the waveform confirms looseness of the shaft in the housing by means of a very graphical representation of the vibration characteristic.



Transients

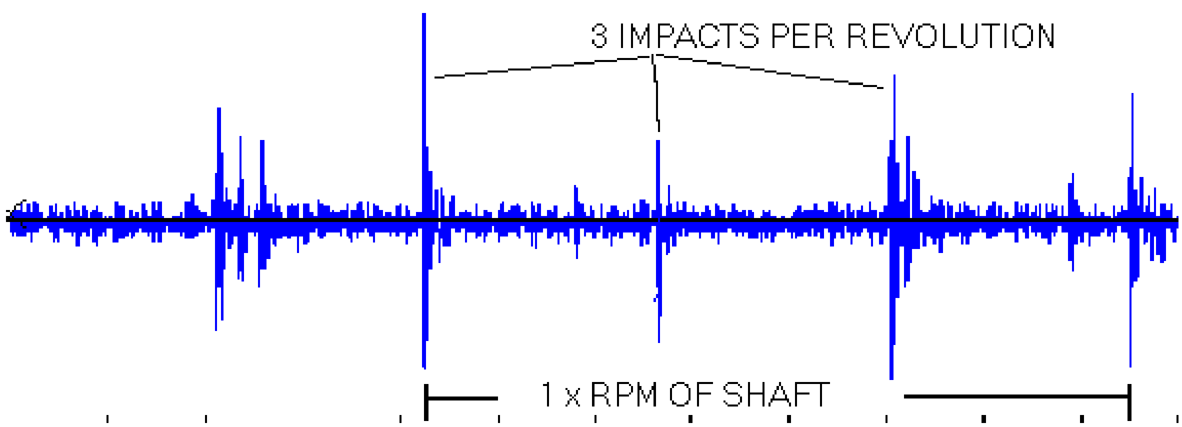
The long event Time Waveform can be used to look at such problems at transients at the start-up condition. The Waveform below was taken on electric motor and it can be seen that this machine is a variable speed variable load motor. As the load is applied, there is a small increase in vibration amplitude, the speed then increases and there is significant evidence that it transits a resonant condition before it reaches acceptable levels at it's rated full load and speed.

The solution in this case was to make a software change to the control system that ensures that the mix of load and speed does not cause this resonant condition to be exited.



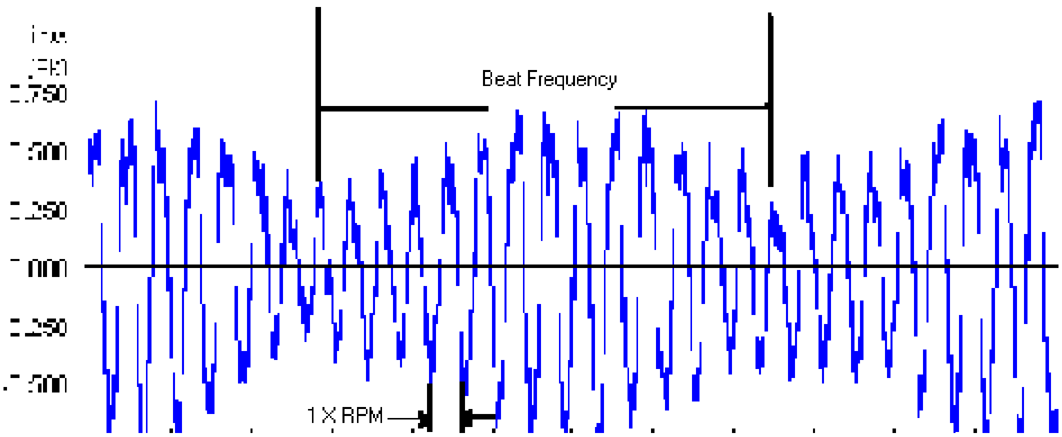
Gear Impacts

The example below was taken from a gearbox on a mill. There are 21 teeth on the pinion and the data clearly shows that there are 3 impacts per revolution. This condition was only detectable by using the Time Waveform as the spectrum showed a very small amplitude at 1 x RPM and a small amplitude at the gearmesh frequency. Without the Time Waveform data this gearbox would have been given a clean sheet and failure would have occurred eventually.



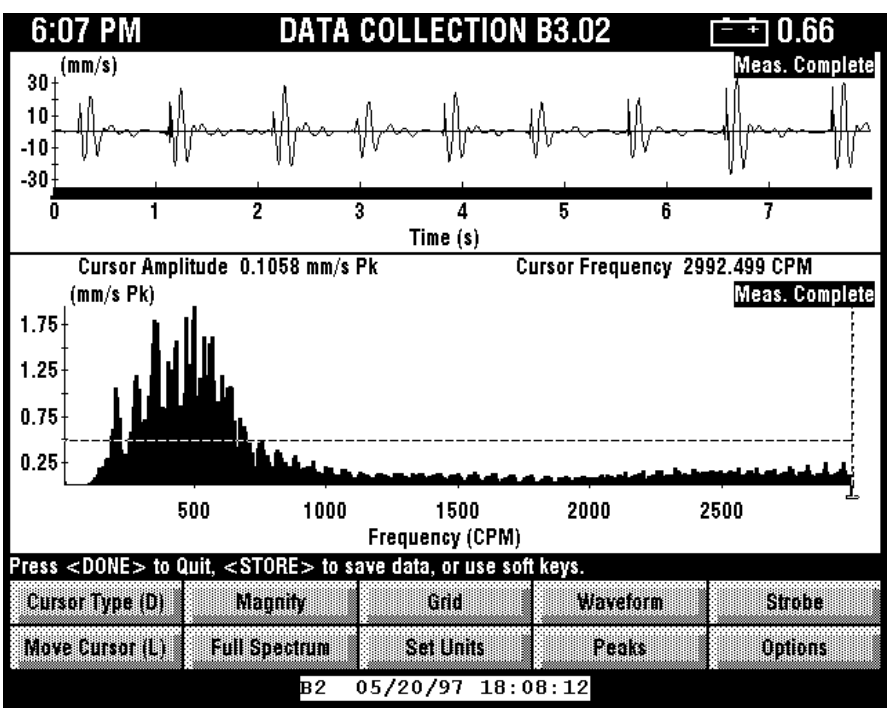
Beat Frequencies

Beat frequencies are caused by closely spaced frequencies acting in phase then out of phase thus causing a modulation to occur. An easy way to analyse this problem is to use the Time Waveform. The modulation effect can clearly be seen in the example below. The closely spaced frequencies of the 1 X RPMs can barely be seen in the tips of the Waveform peaks.



Impactive Vibration at Repetitive Intervals

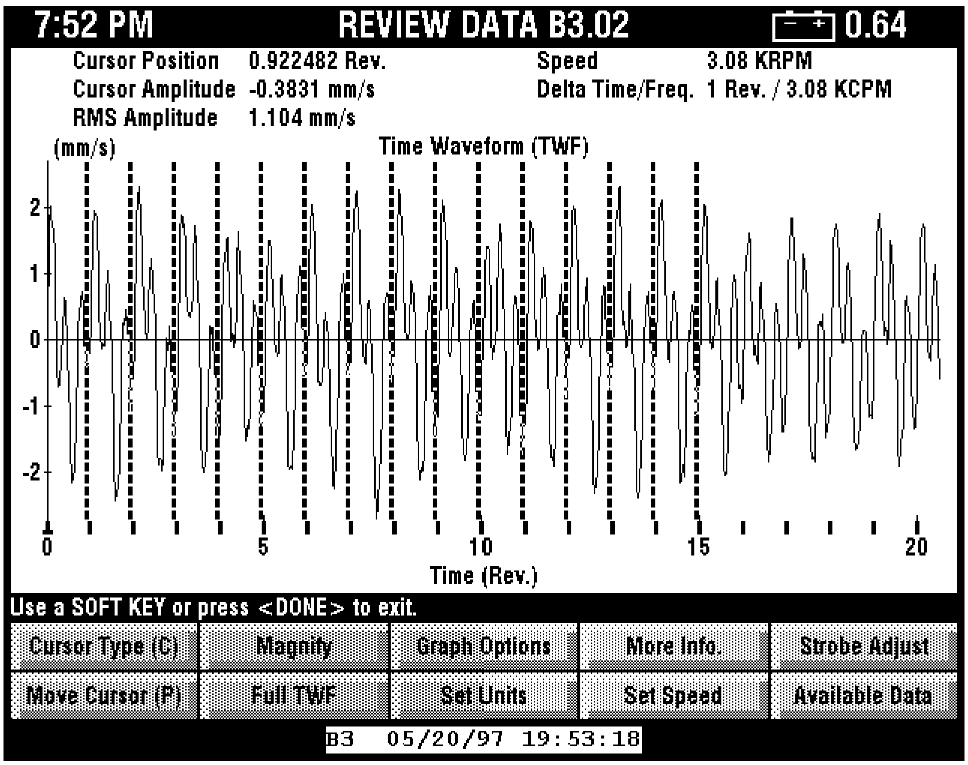
The Spectrum and Time Waveform below are used to illustrate how the Time Waveform can be much more informative with regards to impactive type vibration and it's source.It is very difficult to diagnose the problem from the spectrum except that there is probably an impact that is causing the grouping of peaks around 500 CPM. The Time Waveform, however, shows that there is an impact at an interval of 1 second.



Return to Courtney Beginning Return to Enteract Home Page

Using All Available Tools to Solve the Problem

The most common reason that condition monitoring engineers give for not using the Time Waveform is that they do not understand the time base axis of the plot. The example below shows one of the methods that can be used to turn the data into information. The cyclic cursor option has been selected and it can be seen that there is a vibration at a frequency of 1 x RPM. The cursor has been deliberately displaced to allow the repetitive nature of the waveform to be analysed.



Misalignment and Looseness.

Distinguishing Between Misalignment and Looseness Problems:
A recent development in vibration analysis suggests that the use of Time Waveforms can be used to distinguish between mechanical looseness and misalignment. The basic signature of both problems often will show increased amplitude in 1X, 2X and/or 3X RPM. The advice is that one take a look at the acceleration Time Waveform and compare that with the velocity spectrum to distinguish between the two problems. The acceleration waveform accompanying misalignment will show regular, periodic spacing between major peaks generally occurring at 2X or 3X shaft rotation. In addition the

amplitudes of these peaks will typically follow a pattern as well (that is, for example, one of three major peaks in the waveform may be consistently higher than the others with each shaft revolution - a phenomenon that can clearly be observed in the waveform, but not necessarily in the spectrum).

In addition, if misalignment is a problem, the amplitude level of Time Waveform peaks will normally be less than 2 g's which indicates relatively little impact. In the frequency domain, misalignment will show a lower noise floor which indicates negligible impacting associated with misalignment.

On the other hand, Time Waveforms associated with looseness are characterized by an irregular spacing between the major peaks. In addition, there is no pattern to the amplitude of these peaks -they appear in random variation. Impacts of up to 6 g's, or more in some severe cases. These impacts therefore produce an elevated noise floor in the spectral plot.

Summary

1. Time Waveform analysis should be used strictly in conjunction with spectral analysis as an additional, valuable tool for the analyst.

It may make the difference between vibration data and information

2. Ensure that when you use the Time Waveform that you think in the Time Domain i.e. how long will the problem take to propagate or extend.

3. Use all available features of your analyser to help you with the diagnosis.

4. Do not rely solely on the Time Waveform or the spectrum, use both.

References:

1. Entek IRD International Incorporated Vibration Analysis 2 course.

2. Technical paper, Beats; Stuart Courtney, Entek IRD International Incorporated.