# Overall vibration, severity levels and crest factor plus

## White Paper

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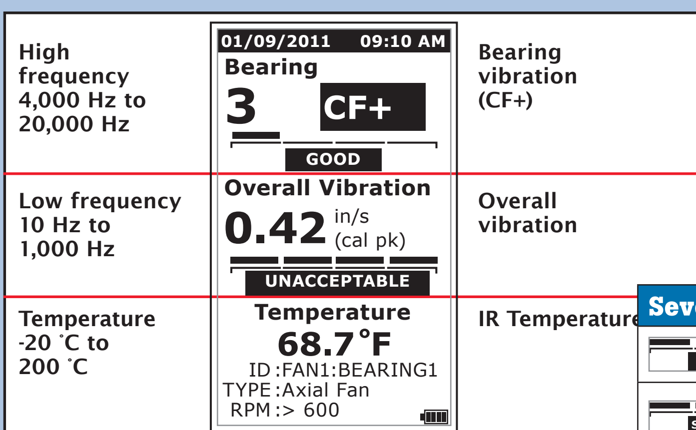



| Severity Scale | |
|---|---|
| GOOD | No immediate repair is recommended. |
| SATISFACTORY | No immediate repair is required. Increase the frequency or measurements and monitor the condition of the machine. |
| UNSATISFACTORY | Have knowledgeable vibration technician conduct more advanced testing at the earliest opportunity. Consider taking maintenance action during the next planned downtown or maintenance period. |
| UNACCEPTABLE | Have knowledgeable vibration technician conduct more advanced testing as soon as possible. Consider immediate shutdown of the machine to make repairs and prevent failure. |

### Introduction

Mechanical Vibration is a notoriously difficult subject matter to master. A quick glance at a textbook in the field shows that the advanced practitioner must master sophisticated concepts in mathematics and physics in order to accurately collect and interpret vibration data. This has caused a major problem for industrial plants – the benefits of a vibration testing program are well known, but far too many plants choose to avoid vibration testing because of the perceived complexity.

Fluke aims to solve this dilemma by developing easy to use vibration products that yield significant benefits without requiring advanced training by end-users. Fluke's first vibration product, released in 2010, was the 810 Vibration Tester (see picture on next page). The 810 is a vibration spectrum analyzer that includes an automated diagnostic engine that identifies the four most common root causes of abnormal machinery vibration: Misalignment, Unbalance, Looseness, and Bearing Faults. The 810 is dramatically easier to use than existing spectrum analyzers because the interpretation of frequency spectrum data is automated. The user simply sees a severity scale for each of the four faults listed above.

Fluke's second vibration product, the 805 Vibration Meter, was released in 2012. The 805 is an overall vibration meter, as compared to a spectrum analyzer like the Fluke 810. The 805 provides the user a simple overall vibration number for both low frequency (10 – 1,000 Hz) and high frequency (4,000 – 20,000 Hz) ranges. In addition to the overall vibration value, the 805 provides a severity scale for both frequency ranges. The low frequency severity scale can be adjusted to reflect the particular type of machine being tested (pump, compressor, etc.), and is a great way to screen for problems such as misalignment, unbalance, looseness, bent rotors, etc. The high frequency severity scale, known as the "Crest Factor Plus" scale, uses a novel proprietary method of processing time domain vibration signals to identify bearing flaws. The 805 also provides the user a non-contact temperature reading for all vibration points tested. The 805 overall vibration meter is a screening tool. Once an adverse vibration condition has been identified by the 805, it is recommended that the team perform more advanced testing to


| | |
|---|---|
| Slight | No repair action is recommended. Retest the machine and monitor condition after maintenance. |
| Moderate | (Months, even up to a year) - No immediate repair action required. Increase the frequency of measurements and monitor the condition of the machine. |
| Serious | (Weeks) - Take maintenance action during the next planned downtime or maintenance period. |
| Extreme | (Days) - Immediate action is required. Consider shutting down the equipment and taking repair action now to avoid failure. |

validate the problem and identify the root cause of the vibration.

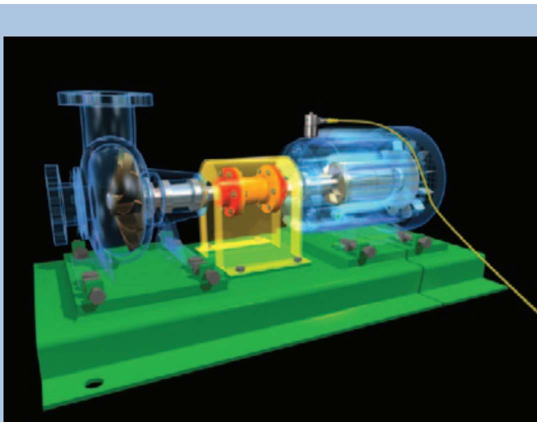
In this white paper, we'll discuss the following topics:

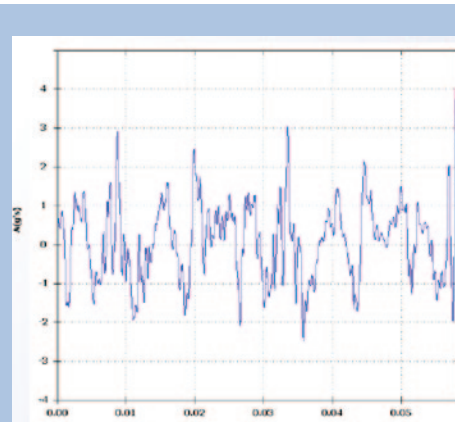
- The difference between frequency spectrum analysis and overall vibration analysis.
- Overall vibration analysis and severity scales
- Crest Factor Plus: High frequency overall vibration analysis and severity scales

## Vibration spectrum analysis vs. overall vibration analysis

All vibration data is collected in the time domain. When using a spectrum analyzer or overall vibration meter, this time domain data is typically collected from a piezoelectric accelerometer. The accelerometer is placed in rigid contact with a vibrating machine. The machine vibration is transferred to the accelerometer, which in turn strains the piezoelectric element within and creates a voltage signal proportional to the vibration. This voltage signal is captured by the spectrum analyzer or overall vibration meter. A sample time domain signal is shown on next page (Fig A). Once the time domain signal has been captured, there are two common analysis methods that can be performed: spectrum analysis or overall vibration analysis.

In spectrum analysis, the time domain signal is transformed into a frequency domain signal using an algorithm known as the Fast Fourier Transform (FFT). A detailed description of the FFT is beyond the scope of this white paper, but in short it reconstructs the time domain signal using a series of harmonic sine waves. The amplitude of each of these sine waves is then plotted against the frequency of the sine waves. The result is known as a frequency spectrum plot. A sample frequency spectrum plot is shown on next page (Fig B). A properly trained vibration analyst can use the frequency spectrum to determine which, if any, machinery flaws exist. The analysis can be somewhat complicated, but a significant benefit is that the root cause of the vibration problem can typically be identified.





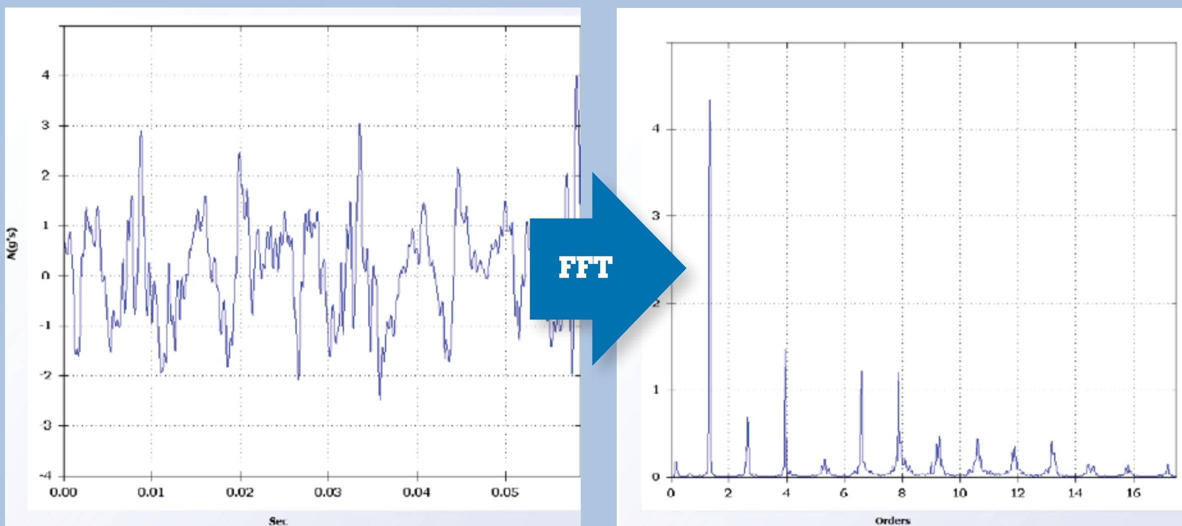



**Figure A** **Figure B**

Overall vibration analysis, by contrast, is much simpler. In overall vibration analysis, the time domain data is used to calculate one single overall vibration value. This single value can be used as an indicator of the overall health of the machine. (Note: there are multiple methods available for calculating the overall vibration value. They are described in the appendix for the interested reader). The benefit of overall vibration analysis is its simplicity – there is only one number to examine. However, there are three limitations of using overall vibration analysis that are worth noting:

- Different machines have different healthy levels of overall vibration.
- Certain machinery flaws, particularly bearing flaws, will not impact the overall vibration value until significant damage has occurred.
- Overall vibration analysis does not identify the root cause of vibration

Despite these limitations, overall vibration meters are still very valuable as a screening tool. Technicians can use them to trend values over time, and if any adverse trends are identified a more thorough analysis (such as spectrum analysis) should be performed to validate the problem and identify the root cause.

It is noteworthy that Fluke has designed the 805 vibration meter to help mitigate these limitations, as discussed on the next page.

## Overall vibration analysis and severity scales

As discussed in the previous section, there are three key limitations of overall vibration analysis. In this section we'll explain a bit more about each of these limitations, and then show how an overall vibration meter can be an effective vibration screening tool despite the limitations. We'll also show how the Fluke 805 vibration meter specifically helps to overcome the three limitations of a conventional vibration pen.

## The three limitations of overall vibration analysis

The first limitation of Overall Vibration Analysis is that different machines have different healthy levels of overall vibration. Rotary blowers, for example, have very high overall vibration levels even when they are in a healthy state. This is caused by the basic mechanical design of the machine, which consists of two parallel shafts with interleaving lobes rotating in synchronization to compress air. By comparison, single-end suction centrifugal pumps (which have only one rotating shaft and an impeller rotating inside of a volute) tend to have very low overall vibration levels in the healthy state. An overall vibration level of 0.300 in/s on the centrifugal pump is indicative of a problem with the machine, whereas that same vibration level on a rotary lobe compressor indicates a healthy machine.

The second limitation of overall vibration analysis is that certain machinery flaws, particularly bearing flaws, will not cause an alarm in the overall vibration level until significant damage has occurred. When a bearing is first starting to fail due to a flaw on the outer race, inner race, or ball/roller, very short duration spikes will appear in the time domain each time the flaw makes contact with an adjacent bearing component. These spikes have very low energy, and therefore cause very little change to the overall vibration value. As the bearing damage progresses, the spikes will continue to increase in energy along with the baseline vibration of the machine, and ultimately will cause the overall vibration value to increase prior to catastrophic failure. However, it would be ideal to identify a bearing flaw early on in the process when the spikes still have low energy, and overall vibration analysis is a poorly suited tool to accomplish this.

The third limitation of overall vibration analysis is that once a severe level of vibration has been detected, it is not possible to determine the root cause of this vibration using overall vibration analysis alone. Frequency spectrum analysis, by comparison, allows the experienced analyst to identify the likely root cause of the vibration by looking for patterns in the spectrum that are indicative of flaws such as unbalance, misalignment, looseness, bearing damage, worn or loose belts, etc.

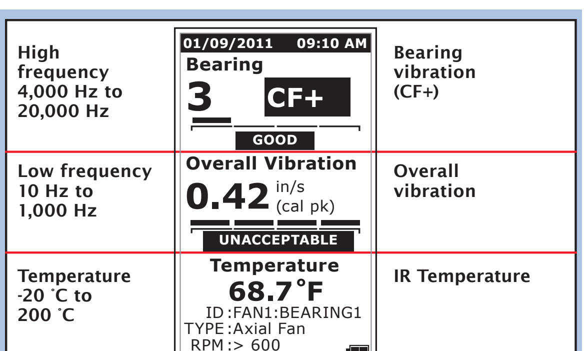
## The value of an overall vibration meter

Despite the limitations listed above, there are many advantages to overall vibration analysis, including:

- Overall vibration analysis does not require extensive training to implement. Nearly any technician can utilize an overall vibration meter, which enables the testing of a much broader base of machines at a plant.
- An overall vibration meter, when used as a screening tool, can very effectively identify machines which should be given more in-depth vibration testing. Any machine that shows an adverse trend in overall vibration level over time, or that shows an abnormally high overall value in any one test, should be tested further using more advanced techniques.
- Overall vibration meters are inexpensive – they can be purchased for about one tenth the cost of a vibration spectrum analyzer.

In addition, to these advantages, Fluke put in a tremendous amount of effort into designing the 805 Vibration Meter such that the limitations of an overall vibration meter are mitigated. For example:

1. The Fluke 805 includes a severity scale for overall vibration for 37 commonly found industrial machinery types (categories). When using the 805, simply select the machine category you are testing from the list within the device and the 805 will provide you with a severity scale showing how severe the overall vibration value you've measured is. Please see the appendix for a listing of the 37 machinery types (categories) covered by the Fluke 805.
2. The Fluke 805 uses a new proprietary algorithm known as "Crest Factor Plus" that identifies bearing flaws much earlier than a simple overall vibration meter is capable of. The Crest Factor Plus algorithm utilizes high accuracy high frequency measurements, and is described in the next section.
3. The Fluke 805 includes the ability to download results to an Excel template for tracking and trending. Although a spectrum analyzer is the best tool for determining the root cause of a high vibration condition, the tracking and trending of overall vibration values is a great way to identify machines which may have flaws and should be considered for more advanced testing.




## Crest factor plus and high frequency severity scales

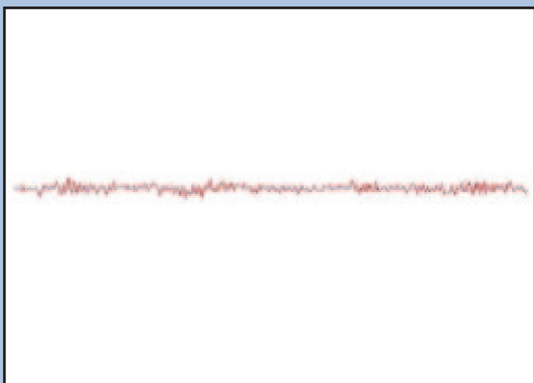
Certain machinery flaws (bearing flaws in particular) don't reveal themselves in an overall vibration value until significant damage has already occurred. This occurs for a simple reason: the early warning signs of a bearing failure are very short duration spikes in the time domain signal. Since these spikes are short in duration, they carry very little energy, and therefore they don't have a significant impact on the overall vibration value.

In an effort to better identify early signs of bearing damage, some overall vibration analysts began using the Crest Factor, which is defined as the ratio of the Peak / RMS of a time domain signal (where the RMS = Root-mean-square). The Crest Factor was actually very good for identifying early signs of bearing failure, because the significant difference between the short duration peak value and the RMS value caused the Crest Factor value to increase rapidly during the early stages of bearing failure. However, a problem occurred as the bearing damage worsened. The significant bearing damage caused the RMS value of the time domain signal to increase significantly. Since RMS is in the denominator of the Crest Factor ratio, this actually caused the Crest Factor value to decrease. Counter-intuitively, the value of the Crest Factor would decrease as bearing damage worsened. The analyst who saw a low Crest Factor value could not be certain whether the bearing was healthy or near failure - clearly not an acceptable state of affairs.

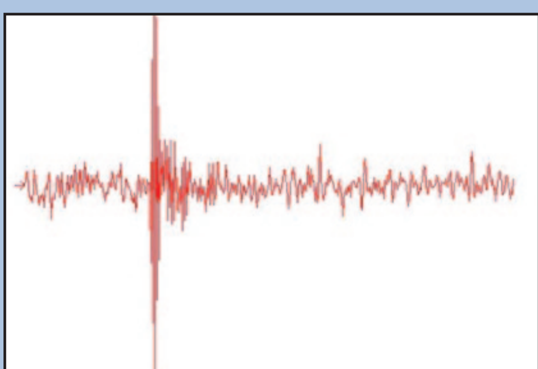
HEAVY BEARING DAMAGE TIME DOMAIN SIGNAL next page– CF level returns to a low value, but CF+ level is high.

In an effort to overcome this problem with Crest Factor analysis, the Fluke 805 utilizes a proprietary algorithm known as "Crest Factor Plus". Crest Factor Plus values can be related to bearing damage according to the following chart:

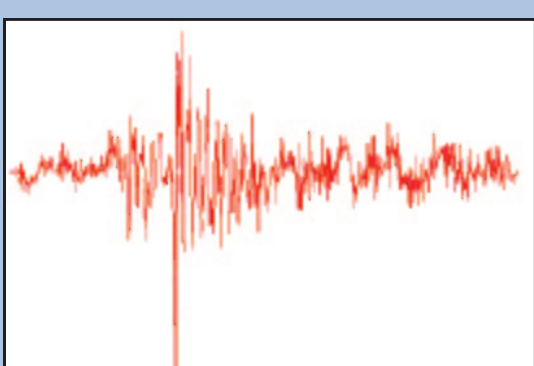
### Healthy time domain signal
Both CF and CF+ levels are low



### Early bearing damage time domain signal
Both CF and CF+ levels are medium



### Heavy bearing damage time domain signal
CF level returns to a low value, but CF+ level is high



| CF+ | Severity |
|---|---|
| 0 to 5 | Good |
| 6 to 10 | Satisfactory |
| 11 to 15 | Unsatisfactory |
| above 15 | Unaccepatable |

The Crest Factor Plus algorithm is a significant step forward from traditional crest factor vibration analysis because the output value (CF+) increases continually as the bearing damage worsens. Some technical details about the algorithm are provided in **Appendix 2**.

## Conclusion
In this white paper we've focused on two vibration analysis methodologies that can be used to examine accelerometer-based vibration data: frequency spectrum analysis and overall vibration analysis. We learned that both methods have strengths and limitations.

Frequency spectrum analysis is ideal for identifying the root cause of a vibration problem, but requires rather advanced training to implement. Fluke designed the 810 to overcome this limitation by including a diagnostic engine that automatically identifies the severity of the four most common machinery problems: misalignment, unbalance, looseness, and bearing damage.

Overall vibration analysis is inexpensive and easy to implement, but faces some key limitations, including: different machine types exhibit different levels of overall vibration in a healthy state; and bearing damage does not impact the overall vibration reading until significant damage has occurred. Fluke designed the 805 to overcome these two problems, respectively, by including severity scales tailored to 37 different machine categories and by including the Crest Factor Plus algorithm for earlier detection of bearing flaws.

In a robust predictive maintenance program, both frequency spectrum analysis and overall vibration analysis have their proper place. Both tools should be used in conjunction to identify machinery flaws early so that corrective action can be taken prior to machine failure.

## Appendix 1: Methods for calculating the overall vibration value

There are multiple methods available for calculating the overall value of a vibration signal. The key differences are:

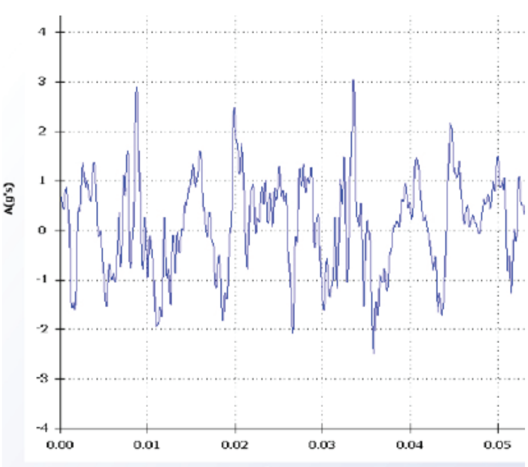
- Peak vs. RMS
- Time domain vs. frequency domain
- Units: Acceleration vs. velocity vs. displacement

**Peak vs. RMS**

Overall vibration can be expressed as either a peak or an RMS value. The peak value is simply defined as the absolute value of the highest magnitude peak above or below the origin in a time domain signal. In the time waveform show below the peak value is approximately 4.0 because the highest peak is 4.0 units away from the origin. The RMS value, by contrast, is calculated using all of the values in the time waveform according to the following formula:

$$RMS = \sqrt{\frac{1}{2}\sum x^2(t)}$$

where x(t) are the individual values of the time series data.




**Time Domain vs. Frequency Domain**

The RMS value of a vibration signal can actually be calculated in the time domain or the frequency domain. The equation above shows how to calculate in the time domain. Parseval's theorem guarantees that we would obtain the same exact value if we calculated the RMS value in the frequency domain as follows:

$$RMS = \sqrt{\frac{1}{2}\sum x^2(t)} = \sqrt{\frac{1}{n^2}\sum |X(f)|^2}$$

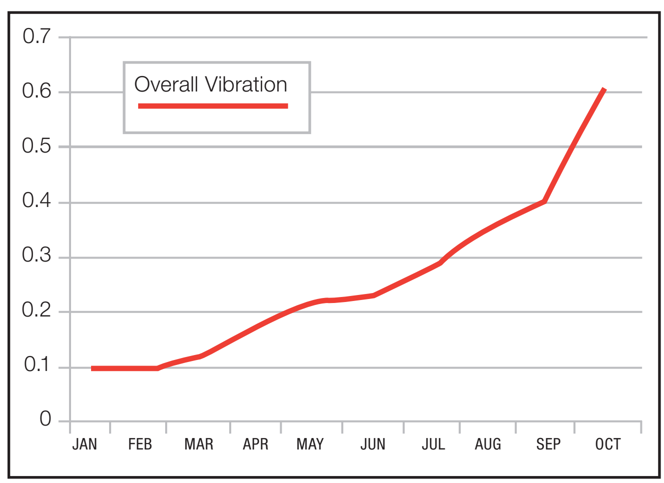
where X(f) is simply the fourier transform of the time series signal x(t).

**Units: Acceleration vs. velocity vs. displacement**

The overall vibration can also be expressed in different units: Acceleration [most commonly expressed in g's], Velocity [most commonly expressed in $\frac{in}{s}$ or $\frac{mm}{s}$], or Displacement [most commonly expressed in mils (i.e. thousandths of an inch) or µm (micro-meters)]. By definition, accelerometers collect time series data in acceleration units. Therefore, accelerometer time series data must be integrated once prior to calculating the overall velocity value, and then again prior to calculating the overall displacement value. Other sensors are available that collect data directly in velocity units (e.g. velocity coils) or in displacement units (e.g. proximity probes), but the Fluke 805 and 810 exclusively use accelerometers.

In summary, when performing overall vibration analysis, always be careful to utilize the same calculation method (peak vs. RMS) and units (acceleration vs. velocity vs. displacement) when comparing two values.

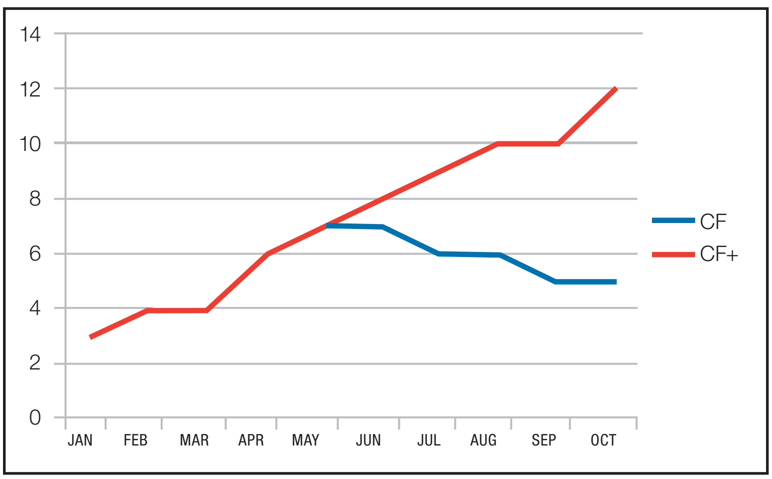
Here is an example plot that shows a trend of Overall Vibration as the machine health worsens.



## Appendix 2: Crest factor plus technical description

$$\text{Crest factor plus} = \alpha_1 \text{ Peak} + \alpha_2 \text{ RMS} + \alpha_3 \frac{\text{Peak}}{\text{RMS}}$$

Here is an example graph that shows ordinary crest factor varying from 3 to 7 and back to 4 as bearing wear worsens, whereas CF+ increases steadily from 3 to 12 as the bearing damage worsens.



## Appendix 3: List of machine categories in the Fluke 805

**CHILLERS (Refrigeration)**
Reciprocating (open motor and compressor separate)
Reciprocating (hermetic motor & compressor)
Centrifugal (hermetic or open motor)

**Fans**
Belt-driven fans 1800 RPM to 3600 RPM
Belt-driven fans 600 RPM to 1799 RPM
General direct drive fans (direct coupled)
Vacuum blowers (belt or direct drive)
Large forced draft fans (fluid film bearings)
Large Induced Draft Fans (fluid film bearings.)
Shaft-mounted integral fan (extended motor shaft)
Axial flow fans (belt or direct drive)

**Cooling tower drives**
Long, hollow drive shaft (motor)
Belt drive (motor & fan)
Direct drive (motor & fan)

**Centrifugal pumps**
Vertical pumps (12' to 20' Height)*
Vertical pumps ( 8' to 12' Height)*
Vertical pumps ( 5' to 8' Height)*
Vertical pumps ( 0' to 5' Height)*
**Direct coupled**
Horizontal centrifugal end suction pumps
Horizontal centrifugal double suction pumps
**Turbine or motor driven**
Boiler feed pumps

* Height from grade to top motor bearing, may be necessary to specify lower alarm for the lower motor bearing and for upper pump bearing (depending on height).

**Positive displacement pumps**
Positive displacement horizontal piston pumps (Under Load)
Positive displacement horizontal gear pumps (Under Load)

**Air compressors**
Reciprocating
Rotary screw
Centrifugal with or without external gearbox
Centrifugal – internal gear (axial meas.)
Centrifugal – internal gear (radial meas.)

**Blowers**
Lobe-type rotary blowers (belt or direct drive)
Multi stage centrifugal blowers (direct drive)

**Generic gearboxes (Rolling element bearings)**
Single stage gearbox

**Machine tools**
Motor
Gearbox input
Gearbox output
Spindles – roughing operations
Spindles – machine finishing
Spindles – critical finishing

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Printed in U.S.A. 3/2013 4314907B_EN