

Cyclic Time Averaging with SKF @ptitude Analyst

Patent: US 06,789,025

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Requirements

This article assumes the reader has good knowledge of the following concepts: Synchronous Time Averaging and Setting up Derived POINTs.

Cyclic Time Averaging is available for the SKF @ptitude Analyst CMSW 7400 software platform only.

Abstract

Cyclic Time Averaging (CTA) is a post process operation that operates on time waveform signals, creating an averaged waveform similar to a Synchronous Time Averaging (STA) measurement. Unlike STA, CTA does not require a trigger and can be computed on already acquired time domain signals. CTA is a technology that can aid in helping to identify fault sources; it is meant to complement the existing array of techniques.

SKF @ptitude Analyst implements CTA through the use of derived POINT functions as well as a visualization technique through an overlay in the time waveform graph. This article gives an explanation of the CTA process as well as a description of its use through derived POINTs and the time domain overlay.

The CTA process

Cyclic Time Averaging operates within a single time waveform measurement. It recognizes the fact that a single measurement often contains many cycles of the defect being monitored and therefore exploits the opportunity to average these cycles and form a new, averaged time domain waveform.

Consider the raw waveform of **fig. 1**. The waveform captured shows about nine to ten cycles of a sine waveform with significant amount of noise.

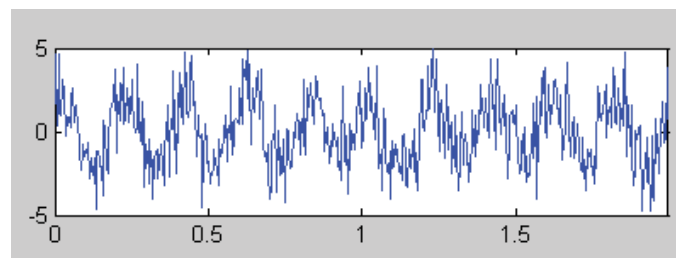


Figure 1. Raw waveform showing about nine defect cycles with noise.

If we want to reduce the noise level by means of Synchronous Time Averaging, we can acquire the signal with, for example, eight averages. STA requires a data acquisition device that is capable of taking triggered measurements. Taking eight averages means taking eight measurements that are averaged, and therefore the total measurement time in this case is $8 \times 2 = 16$ seconds. The result of this STA averaging process is shown in **fig. 2**.

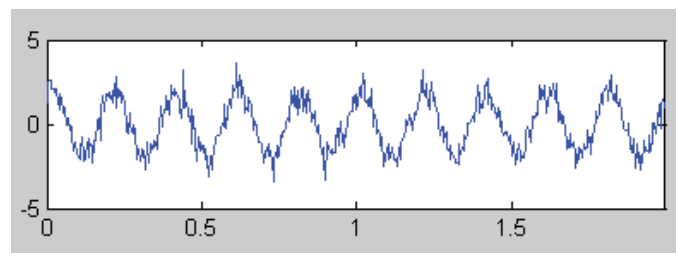


Figure 2. STA measurement with eight averages.



The result shows that noise is reduced significantly and the original sine wave can now be more clearly observed.

Cyclic Time Averaging uses all the defect cycles within a single measurement. It is thereby limited to average as many times as the defect was captured in that measurement, but no special data acquisition device is necessary and the process can be applied any time after data is acquired. CTA takes the first sample of the first defect signal cycle and averages this with the first sample of the next defect cycle and so on and so forth including as many cycles as the entire measurement contains. **Fig. 3** demonstrates this by showing a red arrow pointing to the first sample of each defect cycle. The CTA method is clever enough to align all samples such that their time fits nicely into the defect cycle. It is as if the CTA measurement is a very short time STA measurement operating within the data captured for a single (long) measurement.

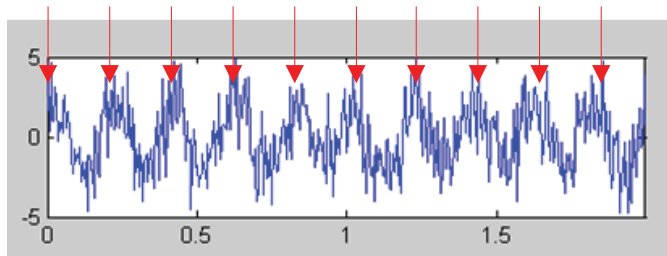


Figure 3. The raw measurement showing the positions of the first sample of each defect cycle.

Perhaps even a more intuitive way to display the time domain is as a cyclic polar plot, whereby the time domain is wrapped around each defect cycle. With this cyclic polar plot, each sample that is measured at the same angle overlaps each other. **Fig. 4a** demonstrates the cyclic polar plot with the same time domain data as in **fig. 3** above. It is now easy to see how noise can be removed by averaging all overlapping cycles. **Fig. 4b** shows the result of the CTA whereby all 10 cycles are averaged. Clearly a much improved signal.

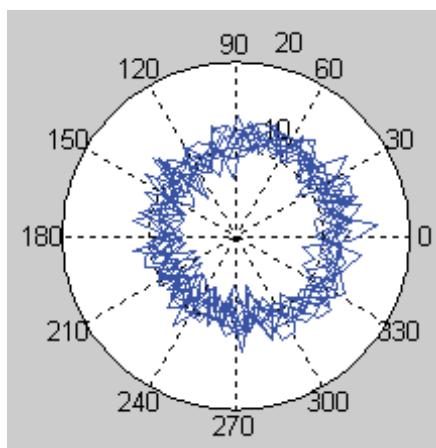


Figure 4a. Cyclic polar plot of raw defect signal.

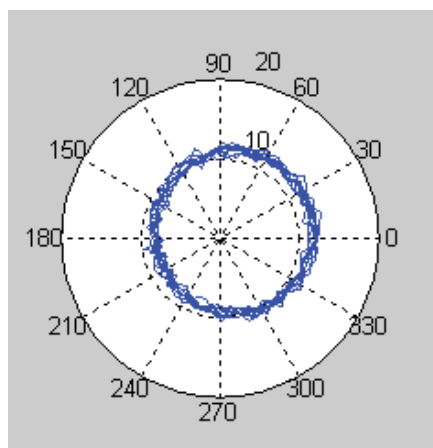


Figure 4b. CTA of raw defect signal.

Advantages of Cyclic Time Averaging

Synchronous Time Averaging requires a trigger for every vibration source of interest. A trigger can be as simple as a notch on the shaft with an eddy current probe as the sensing element, but a trigger can also be fairly elaborate, costly and hard to maintain (i.e., as in the case of felt triggers). In addition, STA measurements require acquisition of the same measurement as many times as the number of averages set for that measurement. Therefore, STA measurements often take a considerable amount of time to acquire. Data acquisition devices that can acquire many channels in parallel can speed up the total process of acquisition, but each STA measurement itself must always be acquired in succession and thereby lasts at least as long as the measurement time multiplied by the number of averages.

In contrast to STA, CTA uses only a single measurement to perform averaging. Consider a measurement length of 10 seconds (not uncommon in the paper industry) and a defect frequency of 5 Hz (200 ms). One single measurement captures $10/0,2 = 50$ cycles of the defect. CTA is able to realign the samples in the measurement so that they can be averaged and a new waveform is created that contains only frequencies synchronous to the source.

CTA can be performed on any time domain measurement as long as this measurement covers more than two revolutions of the defect source under study. CTA is computed as a post measurement process (i.e., it is not a measurement type that needs to be downloaded to the data acquisition device). Therefore, all data acquisition devices that support capturing time domain data are instantly supported by CTA. Due to its post processed nature, one is able to create “what if” scenarios by computing CTA on old data with experimental defect frequency values to troubleshoot complex cases.

As most cyclic processes have a more or less constant ratio, acquiring one speed reference may suffice to determine all others (e.g., in a gearbox, knowing the input shaft speed and the gearbox’s internal gear ratios – all other frequencies can be computed and are known). If the input speed changes, all other speeds change with constant ratios. This means that CTA does not need a great number of actual physical triggers. In addition, some mechanical defects cannot be synchronized with an actual physical trigger (consider a bearing cage for example). CTA can easily synchronize to these events using a derived speed value computed from a known, measured tachometer signal.

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Some sources have a slightly changing speed ratio. For example, a paper machine felt tends to stretch over time. Similarly, a belt may also see some level of stretching, thereby changing the belt repetitive frequency ratio to the driving shaft. CTA can automatically correct for very small speed variations. However, CTA is a strongly discriminating process and large speed deviations are not tolerated. If a large speed deviation is to be expected, an actual physical speed measurement may be best to compute the CTA average.

Synchronous Time Averaging does not always result in a signal that is as clean as desired. This may be due to an inappropriate amount of averages (too low) or due to other factors that affect the noise levels when the measurements are taken. An STA measurement can be “cleaned up” by using CTA on top of this. After all, the time waveform of the STA most often captures a number of defect cycles, and therefore the CTA process can average these further. Obviously, the CTA defect frequency should be set to that of the STA trigger, as all other data is not synchronous and just noise or artifacts of strong asynchronous signals.

It should be pointed out that CTA is not the same as STA under all circumstances. Clearly, the number of averages with CTA is limited to the number of periodic cycles “embedded” in the measurement. Also, the resultant frequency resolution of a CTA waveform may be less than what is desired. However, in many cases, a large number of averages is not required and the flexibility of the CTA measurement often outweighs the costs and time required to set up STA measurements.

Cyclic Time Averaging as a visualization technique

SKF @plitude Analyst 2010 implements CTA as a new cursor overlay in the time domain waveform. The CTA process creates a new (averaged) waveform the interval length of which is determined by two confining cursors. The CTA overlay operates very similarly to the harmonic cursor overlay in the time waveform plot.

The CTA overlay cursor can be started by using the toolbar button or from the “All Overlays” dialog. The cursor positions itself midway on the plot and immediately calculates the averaged waveform using the default settings. **Fig. 5** shows a typical overlay with color choices optimized for this display. The blue signal in **fig. 5** is the raw signal from a gearbox and the red signal is the CTA averaged waveform. The markers that are labeled with a number indicate the repetition of the CTA averaged waveform. They indicate which sections of the raw waveform are used to calculate the CTA waveform.

The CTA averaging process takes the very first raw data sample at the marker indicated by the number (-3) and averages this with the first sample at marker position (-2), etc., all the way to marker position 4. This averaged raw sample forms the first new sample of the CTA waveform, which is depicted between the two middle cursors. The CTA waveform is drawn only between the two middle cursors as it repeats itself between all shown markers.

Notice the feedback area in the top left corner shows the current averaging interval (0,17 seconds) as well as the corresponding repetition frequency, which is one per interval (5,686 Hz). The feedback area also shows a contribution value – this will be explained later in this paper.

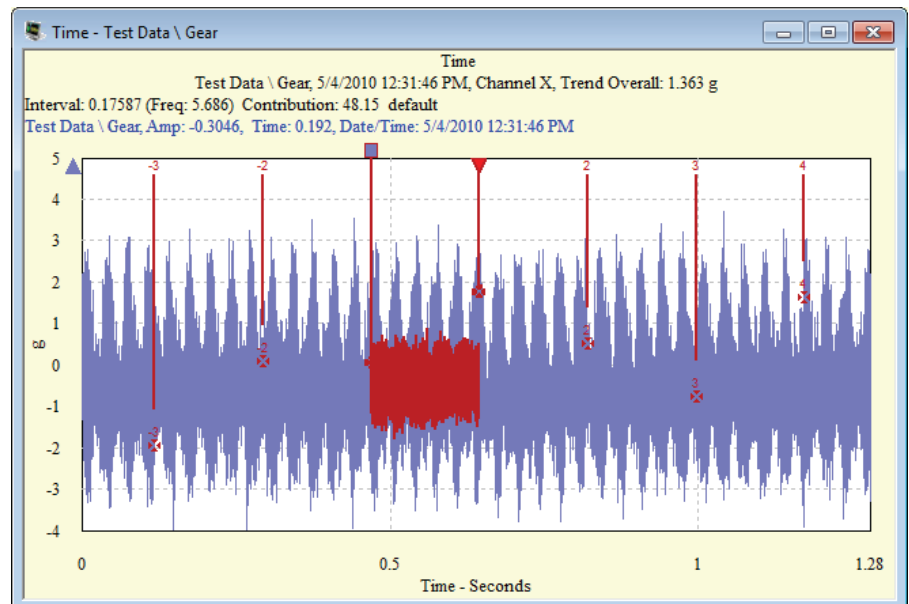


Figure 5. Example CTA cursor overlay.

As with all SKF @ptitude Analyst cursors, you can use the mouse to drag the cursor to a different position. In case of the CTA cursor overlay, the CTA waveform updates instantly to reflect the new averaging interval. **Fig. 6** shows the same waveform as in **fig. 5**, but with a CTA overlay having a shorter interval.

Notice that besides the CTA waveform being shorter, there are many more markers in this plot. The total number of markers can be restricted by the preference setting's "Number of Harmonics" for the time plot. In this case, we have 14 averages from which to compute the CTA overlay (count the sections between the markers).

The CTA cursor overlay can be manipulated with the left and right cursor keys also. First you will need to make either the left or right marker active (indicated by an inverted triangle on top of the marker). You may do this by clicking the marker with the mouse or by using the Page Up / Page Down buttons to toggle the active marker. Then, with an active marker, use the left or right arrow keys to move the marker one step left or right. This effectively changes the averaging interval and the CTA averaged waveform is continually recomputed as you update the interval. The step size is modified by holding down the Shift or Ctrl key and pressing the left / right arrow. With the Shift key, the step size is much bigger and the interval shrinks or grows quickly. With the Ctrl key, the step size is very small, which allows you to hone into very specific frequencies much easier.

To gain better focus on the interval of interest, it may be necessary for you to zoom in around the CTA waveform area. Notice how **fig. 7** shows you a very good close up of the input shaft speed of the gearbox signal (30 Hz).

When the CTA overlay is shown, the Previous and Next Frequency buttons are also active (similar to a harmonic cursor overlay). Using these two buttons allows you to cycle through any frequencies stored as part of the POINT setup.

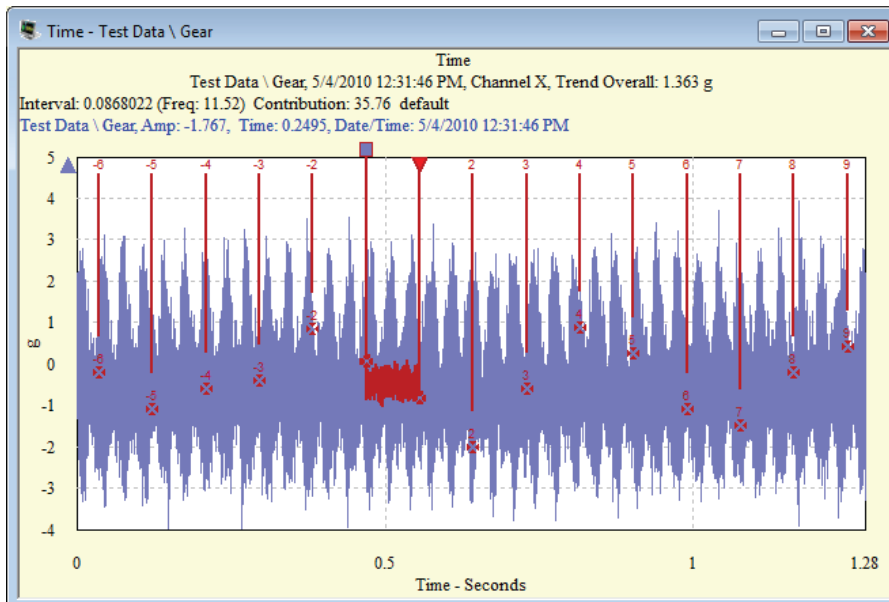


Figure 6. CTA overlay with an interval of 0,08 seconds.

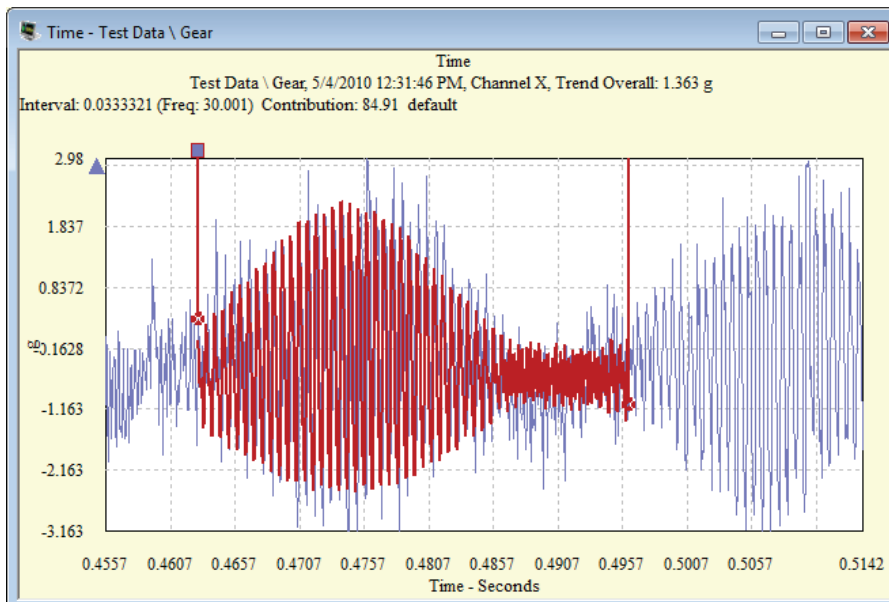


Figure 7. Zoomed in around CTA waveform showing input shaft speed detail. This is the same waveform as in fig. 5 and 6, but the CTA cursor is now set to 1X gear speed.

How to use the CTA cursor overlay

Though the CTA cursor overlay is a very powerful tool for shedding light on artifacts in time waveform measurements, in most cases regular, first review should take place in the spectrum plot. Unbalance, misalignment and bearing defect problems or other impact related signals are generally best reviewed and quickly spotted in the spectrum domain. However, there are a number of problem signals that are very difficult to see or diagnose in the spectrum domain.

Our example shows a gearbox signal from a simple gear with 51/26 teeth, a 30 Hz input speed, and therefore a 58,8 Hz output. The full waveform is shown in **fig. 6** and the detail input speed (30 Hz) in **fig. 7**. The full wave spectrum is shown in **fig. 8**.

Notice that there are quite a number of harmonics of the output shaft speed, suggesting a phenomenon synchronous to the output shaft with an impact-like behavior.

The signal in **fig. 9** shows the CTA overlay set to the 1X output shaft speed. The averaged waveform shows 26 pulses, thereby confirming the number of teeth on the output gear. However, it also shows a rather large spike involving two teeth, suggesting at least one broken or cracked tooth. In addition, the CTA signal shows a large 1X excursion, which may indicate a significant unbalance. The insights the CTA overlay provides are clearer than those gleaned from the spectrum for this type of defect.

Energy contribution

The CTA cursor overlay also computes the energy contribution as a percentage. The value is shown in the second information line immediately after the interval frequency. Energy contribution is calculated as the RMS value of the CTA computed time waveform divided by the RMS value of the raw time waveform. It can be used as a measure of gauging the relative strength or severity of a defect signal being present in the total signal.

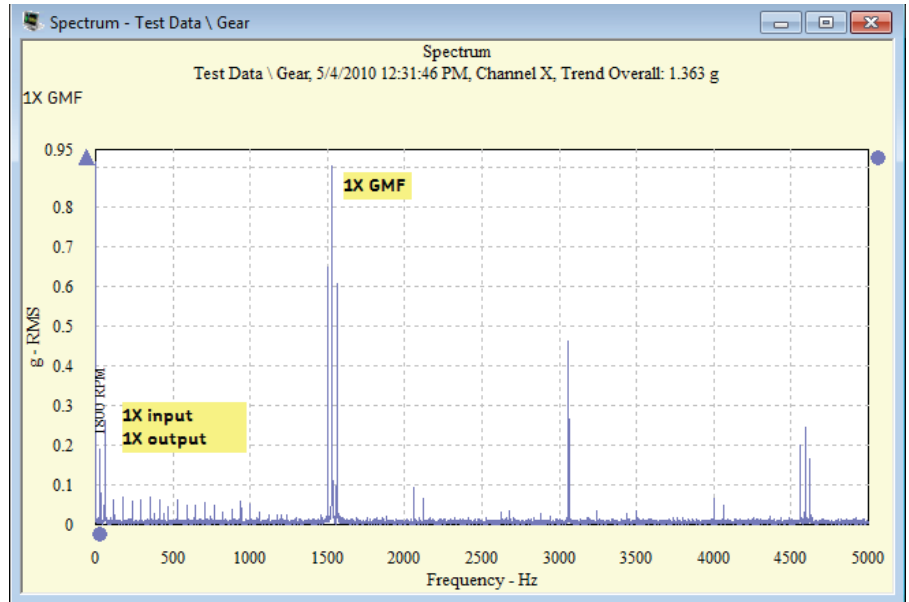


Figure 8. Full wave gearbox spectrum.

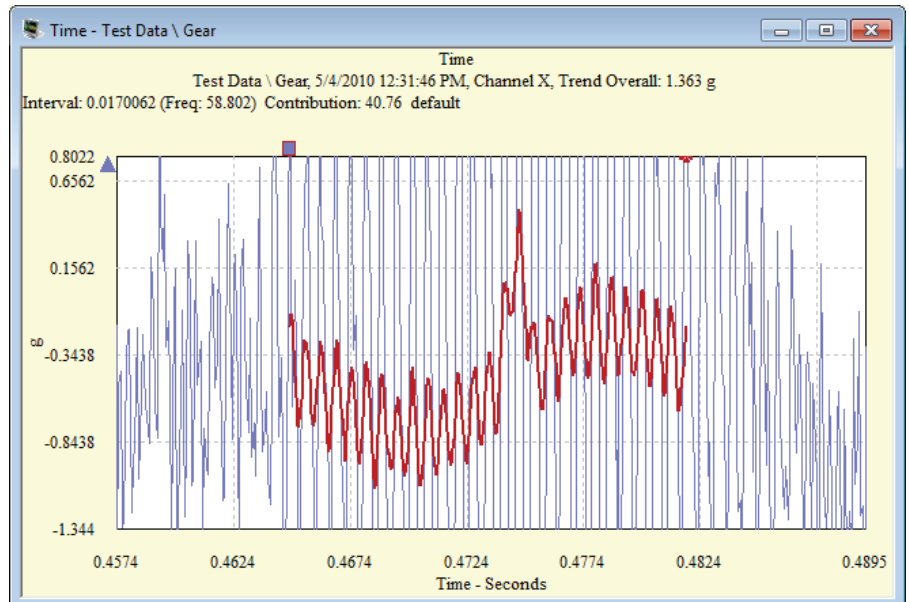


Figure 9. CTA cursor overlay with interval set to 1X output shaft speed.

Cyclic Time Averaging through a derived POINT function

The CTA cursor overlay is useful for visualizations, but if you want to trend (e.g., the RMS value of the CTA waveform), you will need to use a set of special derived POINT functions. There are two functions that provide either the RMS or Peak to Peak value of a CTA processed waveform, and there are two functions that compute the contribution values.

The two derived POINT functions that compute RMS or Peak to Peak values are:

- CTA_RMS(<DYNAMIC VARIABLE> ,<SPEED MULTIPLE>)
- CTA_PK_PK(<DYNAMIC VARIABLE> ,<SPEED MULTIPLE>)

The <DYNAMIC VARIABLE> is a reference to the POINT holding a time domain waveform. The <SPEED MULTIPLE> is a constant factor that is applied to the rotating machine speed associated with the time domain waveform to calculate the averaging period for the CTA calculation. Notice that CTA does not change the engineering unit of the original time domain waveform. So, if CTA is applied to a signal in mm/s, CTA_RMS will report values in mm/s RMS, whereas CTA_PK_PK will report in mm/s pk-pk.

To trend the overall energy associated with the gearbox input shaft speed from **fig. 7**, create a derived POINT with a variable that is associated with the time domain measurements of the appropriate POINT. For this example, the variable is named "GearBoxTWF". Also in this example, the machine speed associated with the time domain waveform equals the input shaft speed, so "speed multiple" can be set to 1.

The derived POINT expression to trend the energy would be:

- CTA_PK_PK(GearBoxTWF, 1)

Or we can trend the output shaft speed by:

- CTA_PK_PK(GearBoxTWF, 51/26)

The two derived POINT functions that compute contribution values are:

- CONTRIBUTION2(<DYNAMIC VARIABLE> ,<SPEED MULTIPLE>)
- CONTRIBUTION3(<DYNAMIC VARIABLE> ,<SPEED MULTIPLE> ,<REF SPEED>)

The definitions for <DYNAMIC VARIABLE> and <SPEED MULTIPLE> are identical as in the CTA functions. <Ref SPEED> in CONTRIBUTION3 allows you to specify a speed reference from a different measurement of a different POINT.

For example, if two POINTs "Input" and "Output" are collecting data across a gearbox, each with their own assigned speeds, one can specify to calculate a contribution value for defect D on the output shaft measurements using the input shaft speed. This can be very handy if defect D is really associated with the input shaft and one wishes to determine its "visibility" or "effect" on output shaft. The expression would be:

- CONTRIBUTION3(GearBoxOutputTWF, 51/26, SPEED(GearBoxInputTWF))

Notice that this expression uses the SPEED() function, which simply extracts the machine speed value from a given dynamic measurement.

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