Understanding Vector, Gap, and Waveform Data Compensation

By: Richard Thomas
Principal Engineer, Machinery Diagnostic Services
SETPOINT™ Vibration

Introduction

Proximity probes are sensitive to the electrical and magnetic properties of the target being observed and are incapable of distinguishing between actual vibration and shaft runout caused by physical and mechanical deformation in the shaft material. Runout introduces error into the measured vibration data from a proximity probe. In order to minimize the effect of runout, industry standards have been established which define maximum acceptable limits of shaft runout in the probe track area[1]. In order to provide accurate machinery diagnostics as well as machinery management, it is imperative that runout be removed from the measured vibration data prior to performing any analysis of the data.

Shaft runout is the error between the actual and indicated shaft centerline positions and is usually the result of a combination of mechanical and electrical causes.

- **Mechanical runout** in the probe track area occurs when the observed probe surface and/or journal surface is not perfectly round or there are concentricity errors between the probe target and journal surface areas. Mechanical runout can be directly measured with a dial indicator.

- **Electrical runout** in the probe track area is caused by:
    - variations in temperature and conductivity of the steel
    - variations in the magnetic permeability of the steel
    - segregation of the steel
    - inclusions in the steel
    - variations in surface stress during heat-treating
    - burned areas due to grinding

1. nX Slow Roll Vector[2] Compensation

The nX slow roll vector represents non-dynamic motion as observed by the proximity probe. The nX slow roll vector will be different for each measurement transducer location. It consists of both mechanical and electrical runout effects. It will distort and obscure the machine's dynamic response data. For purposes of this discussion, we will focus on 1X data. Slow roll vector compensation is usually applied to:

- Bode plots
- Polar plots
- Filtered time base data plots
- Filtered orbit data plots.

Refer to Figures 1 and 2. Slow roll compensation is the subtraction of the slow roll vector from the measured vibration vector[3]. To measure the slow roll vector, we must be able to find an operating condition where the slow roll amplitude is the dominant component of the measured signal. The slow roll speed range is that range of low rotor speeds where the dynamic response (vibration) is insignificant and any measured response measured at these low speeds is assumed to result from runout. The slow roll speed range is best identified by using an uncompensated Bode plot from a machine startup or

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[1] Probe track area is the surface area of the shaft directly observed by the proximity probe.

[2] n = 1.2, 3,…n; X = harmonic of running speed; i.e. 1X = running speed, 2X = twice running speed, etc.

[3] From the same transducer at the same angular and longitudinal location along the rotor

shutdown[4]. From the uncompensated, 1X Bode plot, the slow roll speed range is identified as being from the slowest, stable, running speed of the machine (typically 100-300 rpm) to the speed where dynamic motion (vibration) becomes apparent. Once the slow roll speed range has been established, a 1X vector from within the slow roll speed range is selected and saved as the slow roll vector. It is then utilized by CMS to produce the requisite 1X compensated data plots.

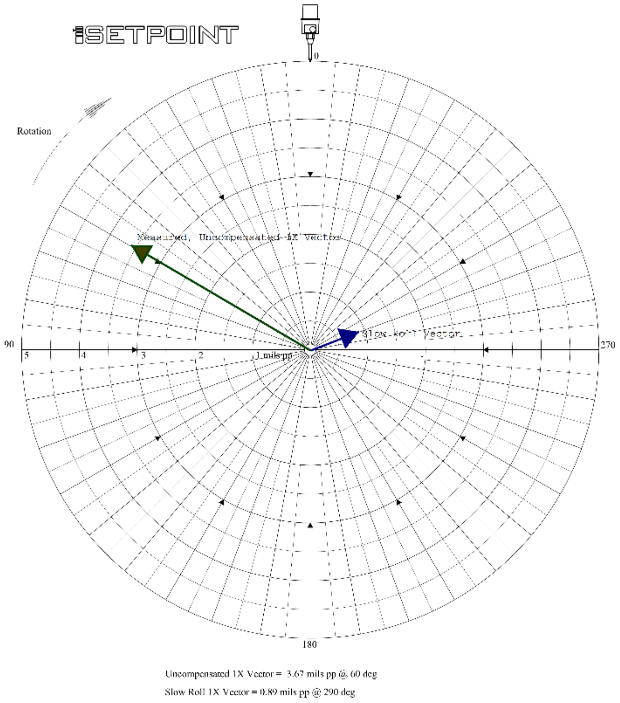

Figure 1: The 1X slow roll vector (blue), in this example, subtracts from the actual 1X response vector, resulting in a measured vibration vector (green) that is significantly different from the actual 1X vector. Slow roll vector compensation can be applied to any harmonic of running speed.

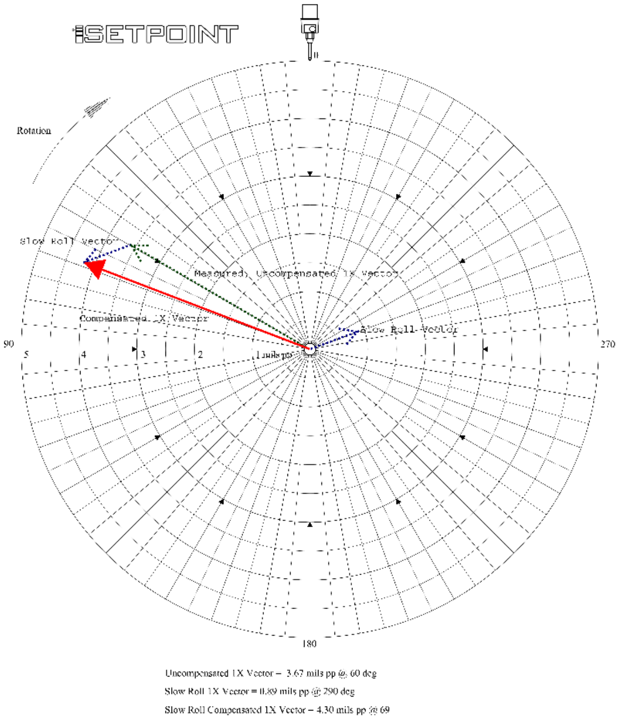

Figure 2 Slow roll vector compensation: To compensate for 1X slow roll, subtract the 1X slow roll vector (blue) from the measured 1X vibration vector (green). The resultant, 1X, slow-roll-compensated vector (red) is the actual filtered vibration at running speed.

2. **Slow Roll Waveform Compensation**

Slow roll waveform compensation provides the capability to digitally “memorize” an unfiltered (direct) slow roll waveform and digitally subtract it from dynamic waveforms at different machine speeds and operating conditions.

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[4] When available, it is always preferable to utilize hot shutdown data as opposed to cold startup data for establishing the correct, actual, operating condition slow roll values. Rotor axial thermal growth at times is significant, which could result in a different observed shaft runout surface cold vs. hot. This is true for nX vector slow roll compensation, slow roll waveform compensation, as well as establishing the 0 speed reference value for shaft average centerline data plots.

Each unfiltered time base waveform consists of a sequence of digitally sampled values. Once a suitable slow roll waveform has been selected, the digitally stored slow roll sample values can be subtracted from the corresponding digital sample values in the unfiltered time base waveforms at different machine speeds and operating conditions[5].

Slow roll waveform compensation has the advantage of removing +95% of the total slow roll signal. Slow roll waveform compensation will remove both sub synchronous and super synchronous frequencies, including signal artifacts due to surface defects, imperfections, scratches, etc.

Waveform compensation can be applied to unfiltered:

- time base data plots
- orbit data plots
- synchronously sampled spectra data plots (spectra plotted as orders of running speed)

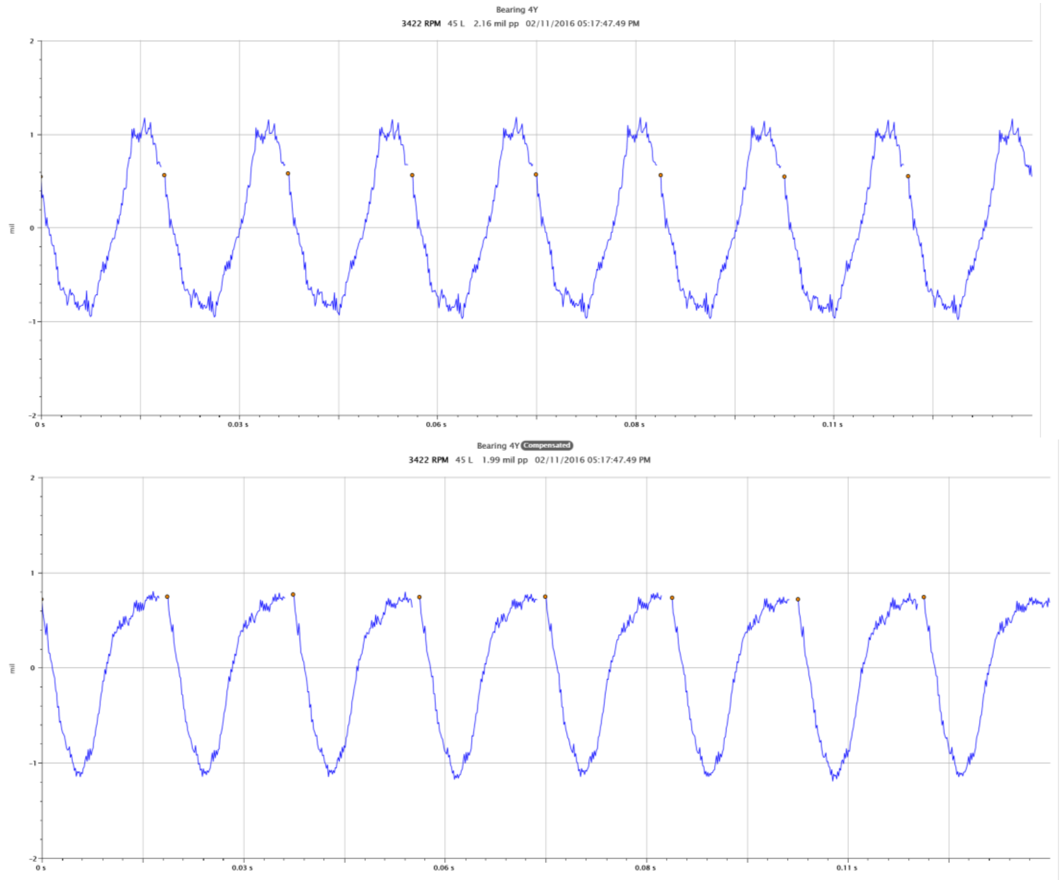

Figure 3 Slow Roll Waveform Compensation: Uncompensated waveform (top); slow roll waveform compensated waveform (bottom)

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[5] The phase trigger event is used as the timing reference.

3. **DC Voltage Reference for the Average Shaft Centerline Data Plot**

Average Shaft Centerline Data Plots are designed to show changes in the average radial position of the shaft; thus, the plot is effectively low-pass filtered and does not display dynamic (vibration) data. However, when the information contained within the average shaft centerline plot is combined with other information such as known bearing and seal clearances, shaft orbit data, process information, etc. a detailed picture of shaft motion relative to bearing and seal clearances and/or radial loading is obtained.

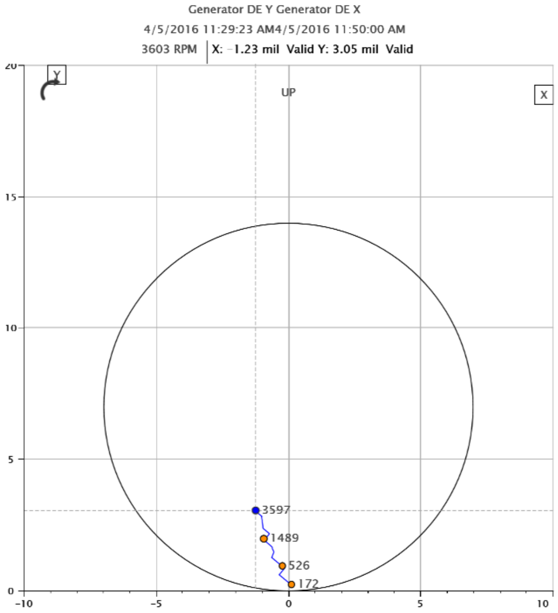

Figure 4 Average Shaft Centerline Data Plot: For a horizontal machine, rotor is assumed to be centered at the bottom of the bearing at low speed; i.e. 0, 0 position. In this particular data plot, the DC reference gap volt data was acquired during hot shutdown at 25 rpm.

The Average Shaft Centerline data plot, although most often used to display changes in shaft radial position versus speed, can also be used to display changes in shaft radial position versus time, allowing for correlation to changing operating conditions, i.e. load, extraction flow, etc. There are two pieces of information always available from the output of a proximity probe transducer. First is the *"AC"*[6] or more correctly stated, the instantaneously varying DC voltage which is proportional to the dynamic motion of the shaft, i.e. vibration. The DC gap voltage is directly proportional to the average distance from the probe tip to the target (shaft). The average position information is contained in the DC gap voltage of the transducers over the linear range for which they operate.

The Average Shaft Centerline Data Plot depicts changes in the average radial position of the shaft centerline in two dimensions and is constructed from the DC gap voltage part of the proximity probe transducer signals. This average position information from two, orthogonal, coplanar transducers is combined to produce a point on a XY (Cartesian) plot. The point represents the shaft at a particular location inside the bearing clearance (circle in the data plot). When a set of this data is collected versus time or speed, the plot becomes an Average Shaft Centerline plot. The plot has equal scaling in both horizontal and vertical directions and is square in shape. Shaft rotation and plot orientation references are indicated at the top of the plot. For a horizontally oriented machine, "Up" is normally used as the orientation reference to free space. The direction of shaft rotation is also referenced to the established view of the machine train.

Reference data for the average shaft centerline data plot is established by documenting transducer DC gap voltage data at either zero rpm or at very low rpm. Once the reference data has been selected, the average shaft centerline data plot is generated with the DC gap volt reference data equating to the 0, 0

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[6] The dynamic (vibration) signal from a proximity transducer is commonly referred to as the "AC" component of the signal from the proximity probe. In reality, it is not an AC signal since the polarity of the voltage does not fluctuate between + and – values. The dynamic signal from a proximity transducer is a varying, DC signal.

position on the plot. Changes in the shaft radial position (changes in DC gap volt data) are then plotted relative to the 0, 0 reference position.

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SETPOINT™

2243 Park Place, Suite A
Minden, NV 89423 USA
+1 775.552.3110
www.setpointvibration.com
info@setpointvibration.com