Rotor Dynamics
Measurement Techniques

Product Note: Agilent 35670A-1

Use the 35670A Data Demonstration Disk (pub. no. 5966-0518E) with this product note and a 35670A Dynamic Signal Analyzer

Agilent Technologies
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Contents

About the author:

John Jensen is a graduate of San Francisco State University, BS in Engineering Science, 1969. He joined Agilent Technologies shortly after graduating and has over 28 years of practical experience in physical measurements. During that time John has pioneered the use of electronic test and measurement equipment in electro-mechanical and control system applications. A prolific author, he has written application notes and technical articles for a variety of publications.

Mr. Jensen's technical expertise includes extensive work and publication on a variety of subjects including:

• Servo Mechanism Testing
• Ultrasonic Wire Bonding,
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John believes that the challenge of improving product and process performance through the use of test and measurement techniques and equipment is the most rewarding portion of his work for Agilent Technologies. He currently provides technical consulting and support for the complete range of Agilent Technologies' Dynamic Signal Analyzers, Laser positioning systems, Vector Signal Analyzers and Spectrum, Network and Impedance Analyzer products.

John currently makes his home in San Jose, CA. His wife and 2 children keep life varied and interesting. When not making machinery measurements John pursues his hobbies of woodworking, travel and gold mining.

Section 1
Introduction

This product note is a hands-on tutorial that walks you through implementing often-used data error correction, reduction, and formatting techniques used in rotating machinery diagnostics. The examples will assist prospective users in evaluating an Agilent Dynamic Signal Analyzer (DSA) for use in rotating machinery analysis, and veteran users will acquire new tools and techniques to more accurately and rapidly determine a machine's condition. The purpose of the note is to show you how to use Computed Order Analysis and Waveform Math in Agilent DSAs to assist you in extracting the maximum amount of information available from machine vibration measurements. Using one instrument with a single user interface to capture and reduce the data minimizes the number of incompatible test instruments needed to measure and document a machine's behavior. The diagnostician can more

quickly isolate the probable cause from all the possible causes of excessive machine vibration. The note walks you through the data reduction process using setup states and runup vibration data on the 3½" floppy disk (p/n 5966-0518E).

The topics covered are:

• Phase Scaling Convention and Conversion
• Slow Roll Removal From X-Y Order Records
• Slow Roll Removal From Orbits
• Orbit Rotation To Horizontal and Vertical
• Slow Roll Compensation of Bodé Plots
• Shaft Centerline Position Versus RPM and/or Time
• Magnitude, Phase, and RPM Numerical Display

Two additional sections cover proximity probes and tachometer/keyphasor interfacing issues with the 35670A DSA. Each section includes step-by-step examples that will assist you in implementing these functions on an 35670A DSA. The examples at the end of each section start by recalling time capture data, measurement state, and the waveform math functions to produce results quickly. Then the example walks you through changes to the data reduction setup state variables and display setups to obtain the results. The changes will illustrate how easy it is to modify the measurement state and the effects on the results. The complete manual setup sequence is provided when appropriate. This approach is intended to provide the background and an understanding of the technique, as well as to help you find your way around in the DSA. It is hoped that with a better understanding of the functionality in your 35670A, you will be inspired to go beyond what is presented here.

Section 2
Background

In rotating machinery diagnosis, a machine – at best – allows only limited access for vibration measurements. From this limited set of vibration data, the diagnostician must rapidly and accurately extract the information needed to assess a machine's condition. The more information that can be extracted from the vibration data, the better the judgment call on the machine's condition will be. These judgment calls have very expensive consequences, and therefore speed and accuracy are critical to success. This note is intended to show the users of Agilent DSAs how to get the maximum amount of information from the available vibration data set. The diagnostician extracts and enhances the information from the data by removing errors, reducing data using different techniques, and displaying the results in different formats. Each format or display enhances the information in different ways. The diagnostician looks for consistency in the fault indicators and looks for other possible anomalies or contradictions in the machine's vibration response data.

Traditionally, to be able to look at data in multiple ways, the diagnostician needed to bring a variety of widely different kinds of instrumentation to measure and reduce the data. In the past, digital vector filters were used to examine filtered and unfiltered orbits, to make Bodé and polar plots, and read out magnitude, phase and RPM of an order of rotation. A spectrum analyzer was required to provide spectral maps, waterfall spectrums, etc. An analog or digital tape recorder was used to capture data for further analysis. A portable computer and some custom software to control the data acquisition and data reduction were often required. Many times the data reduction tasks were done manually or not at all. This all translated into time-consuming and tedious data reduction tasks requiring many different instruments, all with incompatible and mostly proprietary data formats.

Order tracking analysis evolved using analog/digital tracking filters referred to as digital vector filters (DVFs). The DVFs provided tracking filters with user-selectable bandwidths that were set to track a multiple of the shaft speed. The user needed to optimize the tradeoffs between the RPM ramp rate and selectivity (tracking filter bandwidth.) The DVF provided user-selectable fixed-bandwidth tracking filters. For a bandpass filter with a bandwidth of 60 CPM (1.0 Hz), the output response would reach 63% of the peak in 1 second and 95% of the peak in 3 seconds for a sine wave burst input at the filter's center frequency (Fig. 2.1). The filtered measurement values will lag the true values for signals that are changing amplitude faster than the settling time. DVFs depended on phase locked loop (PLL) technology to track an order of rotation, which made optimizing order selectivity and speed ramp rates more

Fig. 2.1
The step response of an analog tracking filter with a 60 CPM bandwidth filter follows the exponential curve as shown. If the machine's speed ramp rate is too fast for the filter settling time, the indicated vibration levels will be less than their true values.

60 CPM Bandwidth

63%   89%   94%

120 CPM Step Sinewave

time

1 sec   2 sec   3 sec
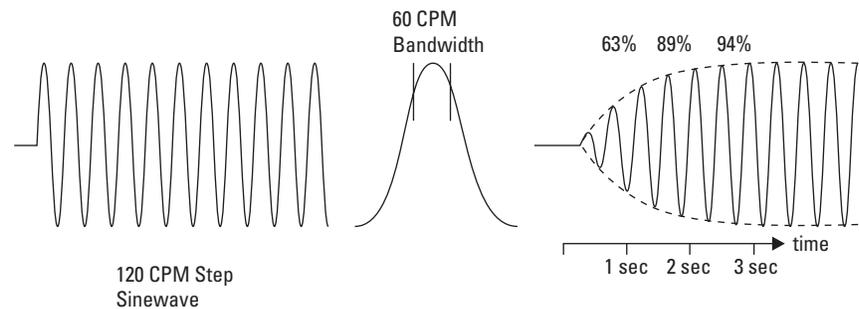
complicated (Fig. 2.2). The DVFs interfaced directly to proximity probes and keyphasor signals as well as to other transducers. The DVF displayed shaft RPM, bearing clearances (gap), and phase angle relative to the once-per-revolution phase reference. Synchronously filtered data could be viewed by connecting an oscilloscope. Bodé and polar plots were produced by connecting to an analog or digital X-Y plotter. The DVFs were real workhorses for vibration analysis and are still much admired for their orbit displays, large numerical readout, and ease of use (Fig. 2.3).

The data acquisition and data reduction speed advantages of the first- and second-generation Fast Fourier Transform-based dynamic signal analyzers made them very attractive prospects for rotating machinery analysis. Some of these early high-end DSAs were equipped with external sampling inputs that could interface with a machine's tach signal and could be triggered from the once-per-revolution keyphasor. An FFT analyzer could measure hundreds of orders at one time, which looked very attractive compared to the one order per channel on a DVF. The realities of doing order tracking required an external tracking ratio synthesizer
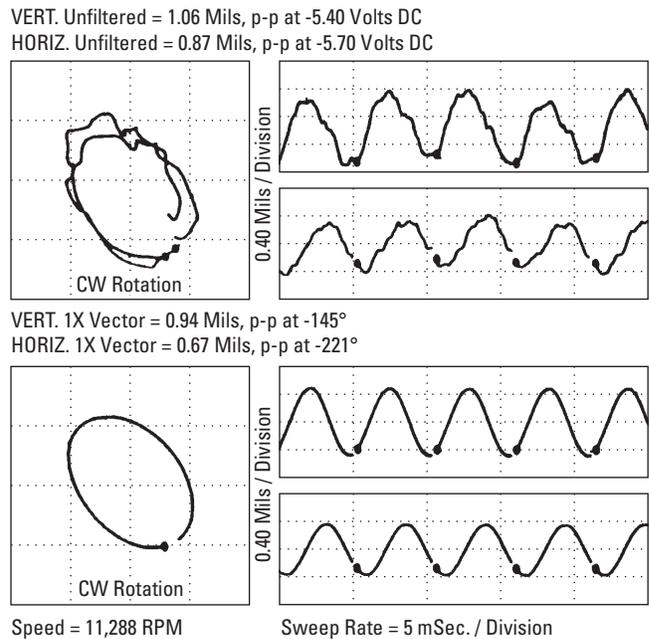
(TRS) to lock the DSA sampling to the tach signal from a rotor. The TRS multiplied the shaft tach so the DSA was sampling at uniform angles of rotation. The FFT works best with 128, 256, or 512 samples per revolution (2^n) and an integer number of revolutions in the data record. It was often worth the difficulties to

install a custom tach (toothed wheel) to provide the needed 2^n pulses per revolution just to eliminate the TRS. The TRS could not maintain perfect lock to the shaft rotation as the speed ramped up. The tracking of RPM over multiple speed ranges was also difficult. A digital tracking low pass filter also was needed to minimize aliasing

Fig. 2.2
The deviation of an "ideal" phase locked loop's estimate of a shaft's angular position from the shaft's actual position for a constant RPM ramp.
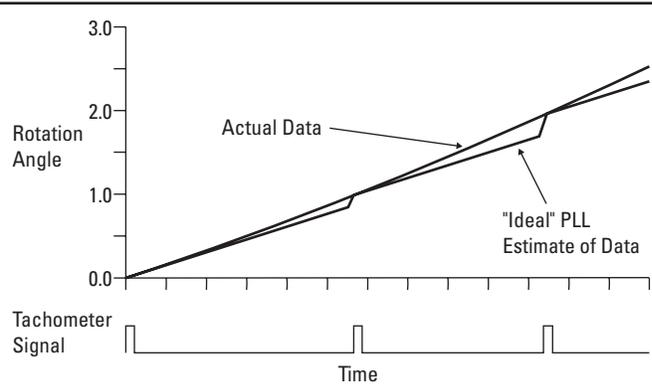
Fig. 2.3
The unfiltered orbits in the upper traces produced the filtered orbits in the lower traces. The DVF tracking filters used PLL to tune to the order being filtered.

VERT. Unfiltered = 1.06 Mils, p-p at -5.40 Volts DC
HORIZ. Unfiltered = 0.87 Mils, p-p at -5.70 Volts DC

CW Rotation

VERT. 1X Vector = 0.94 Mils, p-p at -145°
HORIZ. 1X Vector = 0.67 Mils, p-p at -221°

CW Rotation

Speed = 11,288 RPM

Sweep Rate = 5 mSec. / Division

errors (Fig. 2.4). Since these external devices used phase locked loops to implement both the tracking filter and shaft keyphasor multiplication, the DSA's dynamic range, RPM tracking speed, and trackable speed ranges all suffered. The biggest problem was the variable phase tracking error that was inherent with phase locked loops (Fig. 2.2).
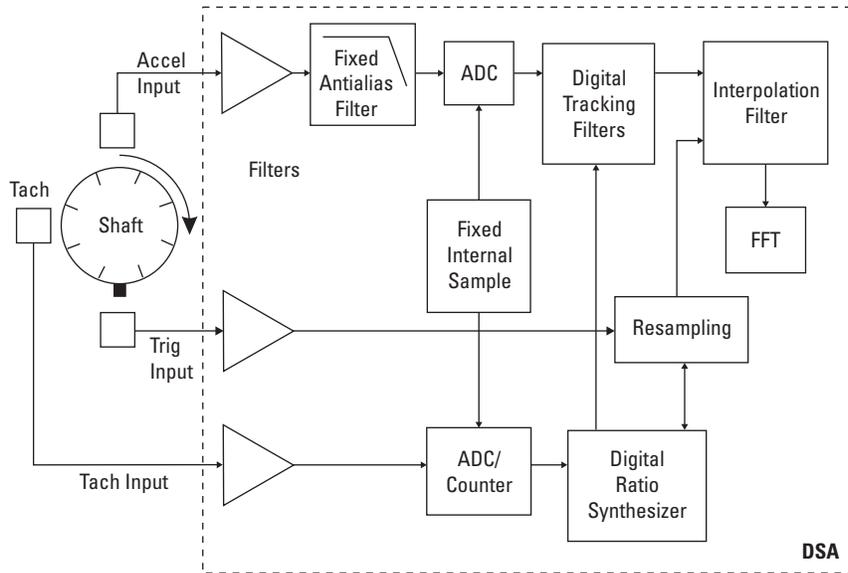
In 1987, Agilent Technologies introduced the breakthrough technology of Computed Order Analysis, which uses the same digital signal processing hardware required for FFT spectrum analysis to implement order analysis*. An elegant digital resampling algorithm now allows Agilent DSAs to do much of the work that once required a DVF, a portable computer, and an oscilloscope (Fig. 2.5).

Computed order analysis overcomes the inherent problems associated with phase locked loop based approaches. One can record a vibration data set from a machine startup transient using the DSA time capture feature and reduce the data in many different ways. One can view orbits, extract Bodé and polar plots on five orders at a time, produce RPM spectral maps, order maps, do slow roll error removal, etc. One can also view time or order data records, easily convert displacement to velocity or make other conversions. All of these

Fig. 2.4
Older DSAs could be configured to do order domain analysis by adding a tracking ratio synthesizer and tracking low pass filters. But tracking accuracy, dynamic range, and speed ramp rate suffered due to phase locked loop implementation in these external boxes.
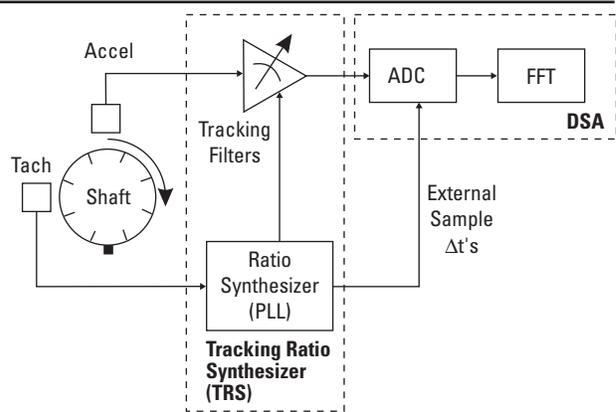
Fig. 2.5
The block diagram of a DSA with digital resampling for Order Domain Analysis looks the same as a standard DSA block diagram with addition of a tach input. The all-digital approach eliminated PLL tracking errors and minimized speed tracking errors. Data accuracy and data dynamic range were also greatly enhanced.

* Agilent Technologies Application Note 243-1
  Introduction to Rotating Machinery Analysis.

Phase Scaling Convention and Conversion

results can often be produced and plotted in less time than it would take to set up and rewind an analog or digital tape recorder. Accurate calibrated results can now be viewed quickly, on site, with a minimum of instrumentation.

The DSA's order tracking and order spectrum filters provide proportional bandwidth (BW) tracking filters. The filter's bandwidth changes with the machine's speed. For example, at 600 CPM (10 Hz) and with a delta order set to 0.1, the DSA's tracking filter bandwidth would be 0.1 X 10 Hz or 1 Hz. Because we are using an FFT to produce these filters, the settling time equivalent for the 1 Hz BW filter is 1 second. At 6000 CPM (100 Hz), the tracking filter BW is 0.1 X 100 Hz or 10 Hz wide. The settling time equivalent would be 0.1 second. The DSA, by default, automatically provides the optimum tracking speed and tracking filter BW. Computed order analysis equips the DSA with measurement capability that can handle higher RPM speed ramp rates with better phase and amplitude accuracy than is possible with phase locked loops.

The vector magnitude and angle are the primary values used to identify the relative size and location of an imbalance (heavy spot) on a rotor. Magnitude and phase changes versus speed (Bodé and polar plots) are the primary tools used to measure rotor critical speeds and to do diagnostic work. The phase convention used in machinery vibration, plane geometry, and the electrical power industry is a 0° to 360° phase lag scale. However, two other phase conventions are also commonly used. They are the 0° to ±180° and the 0° to -360° scales. These three scales are shown in Fig. 3.1. The ±180° convention is commonly used in communication and electronics technology. The 0° to -360° scaling is commonly used in servo mechanism Bodé plots. The

0° to 360° phase lag implies a 0° to -360° scale without the minus sign. The default phase convention used in Agilent DSAs is the ±180° scaling.

Fortunately, all the phase conventions start at the same zero point and are exactly equivalent. Converting from the DSA's default ±180° phase scale to the 0° to 360° phase lag convention used in rotor dynamics is straightforward. It is important to understand these phase conventions in order to effectively communicate. A great deal of machine vibration history was collected with DVFs and plotted with the 0° to 360° phase lag scaling. Standardizing on a phase convention that is consistent with that used for past measurements made by DVFs will minimize communication and

Fig. 3.1
Three phase scaling conventions are in common use: 0° to -360°, 0° to ±180°, and 0° to 360°. The DSA's default scaling of ±180° is easily converted to the 0° to 360° phase lag scaling used by Digital Vector Filters.
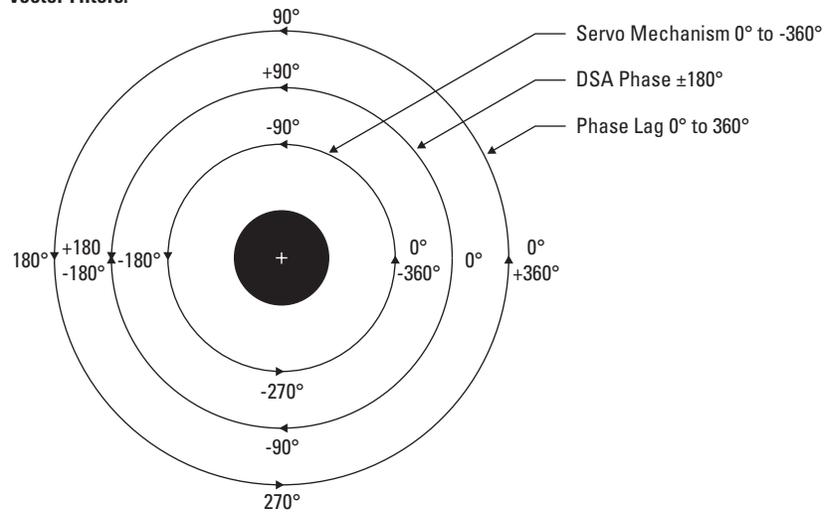
interpretation errors. You should choose and use phase and magnitude scales that are historically consistent. In this manner one can avoid possibly disastrous consequences.

The once-per-revolution phase reference relates the rotating coordinate system of a machine to the stationary coordinate system of the vibration sensor. To illustrate, a simple rotor system with a heavy spot rotating well below the first critical is assumed (Fig. 3.2.) The phase reference trigger point allows the high spot's angular location to be determined relative to the proximity probe. The phase lag angle is determined by looking back in time from the interval ratio between the positive peak of the vibration signal at t_{pk} to the time for one revolution, T. The time goes forward (to the left) and the phase lag is backward (to the right) in time. The phase lag is based on the ratio:

$$\phi = (t_{pk}/T)\ 360°$$

Depicted in Figures 3.2 through 3.5 are ideal vibration signals for four imbalance locations. For a vibration peak (minimum gap) at t_0 in Fig. 3.2, the imbalance is located directly under the proximity probe when the keyway leading edge crosses the phase sensor. For Fig. 3.3, the peak vibration occurs at t_1/T revolutions or 90° counter rotation from the proximity probe location. In other words, the shaft must rotate 90° more after the keyway crosses the phase sensor before the high spot is under the proximity probe. Another way of saying the same thing is to say that the heavy spot is located 90° counter rotation from the proximity probe. Depicted in Fig. 3.4 and 3.5 are imbalances located at 180° (t_2/T) and 270° (t_3/T).

Fig. 3.2
The shaft heavy spot causes a vibration peak (minimum gap) at t_0. The high spot is directly under the proximity probe when the keyway passes across the phase sensor.
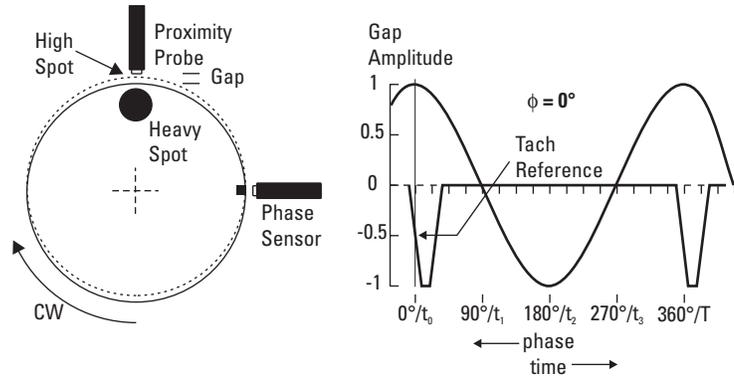
Fig. 3.3
The heavy spot causes a vibration peak (minimum gap) at time t_1. The shaft must rotate 90° clockwise after the keyway passes the phase sensor before the high/heavy spot is under the proximity probe. The heavy spot can be located at 90° counter rotation from the proximity probe.
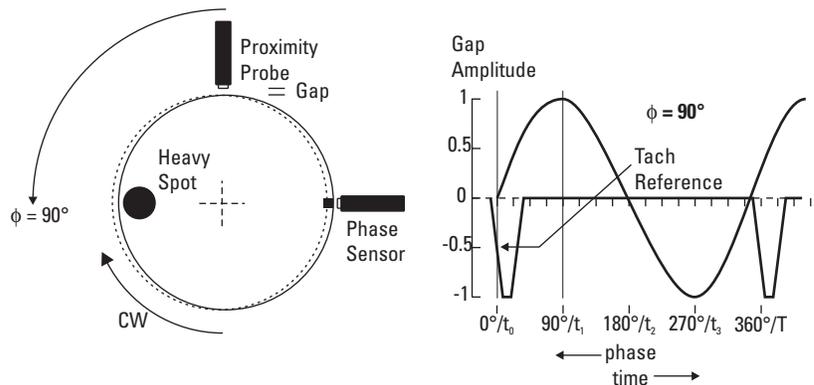
The single most common point of confusion in vibration work centers on the relative location of the heavy spot. From this presentation, it should be clear that phase measurements are relative to the proximity probe, not to the keyway phase sensor. The keyway only provides the trigger point. The phase angle is the number of degrees of rotation the rotor must travel before the heavy spot, or minimum gap, is under the proximity probe.

Converting to Phase Lag using the Agilent 35670A

Phase lag scaling in the 35670A is now a simple matter of going to the Display Format, function Phase Lag On/Off, and toggling it On. The software release A.00.24 and higher adds the phase lag scaling. The details on using phase lag in the 35670A are covered in the example section. The background on the conversion process from one phase convention to another is easily accomplished with the Y-axis scaling function or by selecting phase lag scaling. To convert from the default ±180° scale of the DSA to 0° to -360° scaling, the Y-axis scaling function is used to set 0° top and -360° bottom references. What happens when the phase lag scaling is selected is more complicated.

Fig. 3.4
The heavy spot causes a vibration peak (minimum gap) at time t_2. The shaft must rotate 180° clockwise after the keyway passes the phase sensor before the high/heavy spot is under the proximity probe. The heavy spot can be located at 180° counter rotation from the probe.
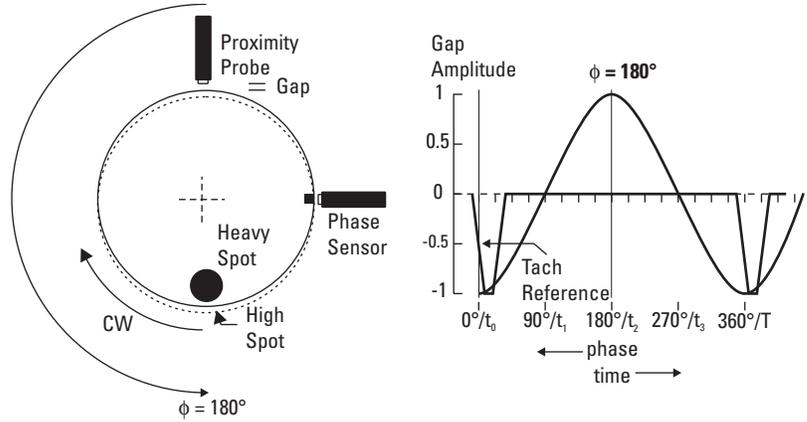
Fig. 3.5
The heavy spot causes a vibration peak (minimum gap) at time t_3. The shaft must rotate 270° clockwise after the keyway passes the phase sensor before the high/heavy spot is under the proximity probe. The heavy spot can be located at 270° counter rotation from the proximity probe.
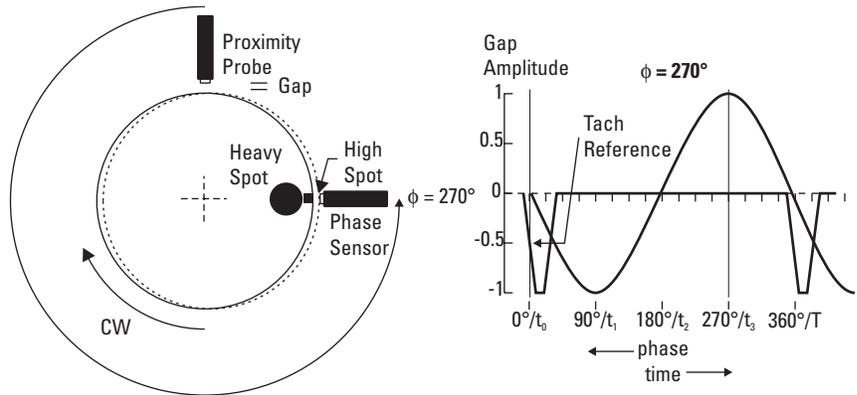
When the phase lag conversion is invoked the phase scale is set to a default of 0° bottom and 360° top. Simultaneously a complex conjugate of the data is calculated. The complex conjugate function changes the sign of the imaginary portion of the complex numbers that are used to represent vectors in rectangular coordinates. The real and imaginary vectors are at right angles to each other and are used to uniquely identify a location in rectangular coordinates. For example, a vector at -30° on the ±180° scale with a magnitude of 1.0 is represented by the vectors 0.866 - j 0.5 in rectangular coordinates (Fig 3.6.) The real part is equal to 0.866, the imaginary part is equal to -0.5, and j = $\sqrt{-1}$. The sine wave that corresponds to this phase angle is shown in Fig. 3.7 and is the same for all phase scaling conventions. The complex conjugate would then be 0.866 + j 0.5 or +30° on the ±180° scale and the 0° to 360° scale. The conjugate process can be said to change the sign of the imaginary vector as in Fig 3.6. The taking of the conjugate of a vector provides the phase lag conversion. The rescaling of the phase range from ±180° to 0° to 360° phase will provide the displays that are consistent with those provided by DVFs. Remember, you do want measurements that are consistent with historical results.

The math is as follows:
$\phi = \{360° - (-30°)\} = 390° \rightarrow +30°$

Fig. 3.6
The vector 1 ∠-30° on the ±180° phase scale is represented by rectangular coordinates (0.8666 - j 0.5). The complex conjugate of this vector is 0.8666 + j 0.5. This vector maps to +30° on both the 0° to 360° and the ±180° scales.
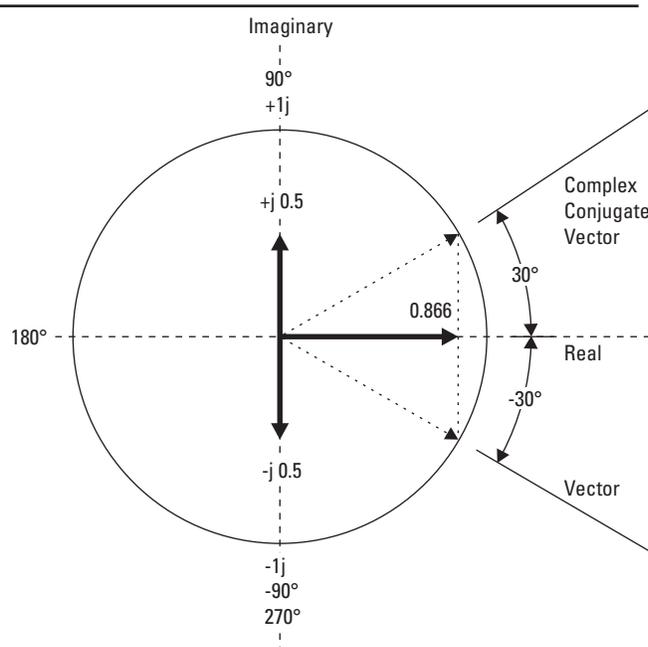
Fig. 3.7
The sine wave with a +30° phase lag has a peak at 1/12 of a revolution (0.08333 revolutions) after the 0 point (phasor leading edge).
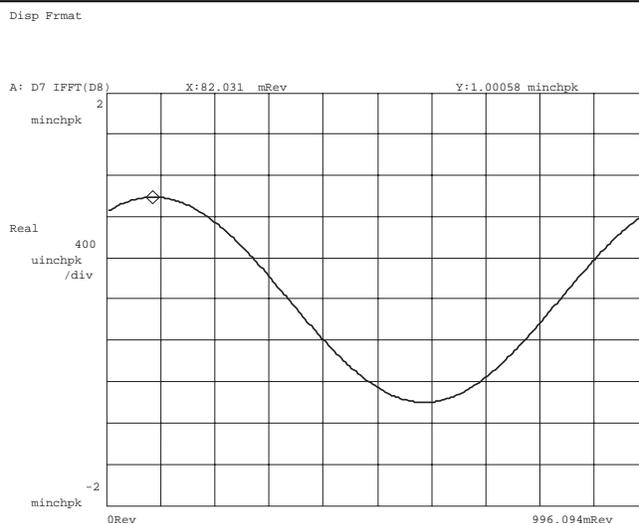
Phase Lag Scaling

The first part of the example covers setting up phase lag scaling in the 35670A with software release A.00.24 and higher. The second part takes you through the vector math to provide an intuitive handle on the phase lag scaling calculation. As an aid in doing the example, the DSA's sequence of commands is called out in a compact notation. The Front Panel push buttons (hard keys) are shown as:

"Hard Keys"

and the soft buttons, F0 through F9, are shown as:

"SOFT KEYS"

A sequence of commands is connected by "→". Commands such as MARKER ON OFF → ON indicate that the function is to be toggled to the ON state.

Setting up phase lag scaling on the 35670A is simply a matter of activating the feature. (Available in firmware release A.00.24 or higher*.) Phase lag is implemented as a user-selected scaling that is applied to all subsequent phase coordinate displays. To activate the scaling press:

Display format → MORE → PHASE LAG ON / OFF → ON

Turning phase lag on will change the scaling and coordinates for all subsequent analyzer measurement modes.

The Phase Lag On can be saved in the instrument state and then recalled. When it is recalled, all phase traces and coordinates will be set to a phase lag range of 0° to 360° for all other measurement modes. If the phase lag scale is the phase convention you wish to use, then save an Autostate with Phase Lag On. At power up the phase lag scale will be activated.

The key path to save an autostate is:

Save/Recall → SAVE MORE → SAVE AUTOSTATE

Note: Autostate will also store any other settings such as displays or input ranges. Be sure your 35670A is set-up to your preferences before storing an Autostate.

The phase scale of 0° bottom, 360° top is the default phase lag trace range, but the user can change the scale to 0° top, 360° bottom. The command sequence is:

Scale → TOP REFERENCE → **0** → BOTTOM → **360**

The phase range can be auto-scaled or an arbitrary range can be set using:

Scale → AUTOSCALE ON OFF → ON or **Scale** → TOP REFERENCE and BOTTOM keys.

All phase plots are labeled PHASE LAG when phase lag is turned on. When

Preset → DO PRESET

are pressed, the phase lag scaling will revert to the default PHASE LAG OFF MODE of scaling (±180°). For the 35670A with older software releases (A.00.21 or lower), phase lag scaling can be implemented using the math function conjugate multiply CONJ( ). The phase scale is set to 0° bottom and to 360° at the top. The state with the phase lag scale and conjugate multiply math function would be saved. When recalled, the math and state/trace can be used to plot phase lag. The 35670A with software rev. A.00.21 or lower will allow a phase scale of 360° top and 0° bottom, which is the most commonly used format for phase lag plots. For the FFT linear resolution and computed order analysis measurement modes in the 35670A, a separate conjugate multiply math function for each measurement result that is to be plotted in phase lag coordinates will be required.

Phase Lag Example

In the example, two simple real-imaginary data records and the conjugate math function are recalled to illustrate the phase lag scale conversion process.

Insert the disk "Agilent 35670A Rotor Dynamics MeasurementsTechniques" into the analyzer.
Press:

> **Save / Recall** → CATALOG ON / OFF → ON

Rotate the marker knob to highlight the file name "PHZLAG.STA".
Press:

> RECALL STATE

Verify that the prompt at the top of the analyzer screen shows "RECALL STATE = PHZLAG.STA".
Press:

> ENTER

The state sets up the Order Analysis measurement mode, display coordinates, and format. The recalled state also sets the time and frequency parameters so the math function operates in sync with the recalled data.

Next, with the disk catalog on the display, rotate the marker knob to highlight the file "PHZLAG.DAT".
Press:

> RECALL DATA → RECALL TRACE AND SCALE → FROM FILE INTO D8.

Verify that "FROM FILE INTO D8 = PHZLAG.DAT" is in the prompt field and then press:

> ENTER

The recalled real-imaginary data will be used to demonstrate the phase lag conversion process using the math function that will be recalled later.

With the disk catalog on the display, rotate the marker knob to highlight file "PHZLG1.DAT" and press:

> FROM FILE INTO D7

Verify that the correct file is in the prompt field and then press

> ENTER

Next, with the disk catalog on the display, rotate the marker knob to highlight the file "PHZLAG.MTH".
Press:

> **Rtn** → **Rtn**

(the button located just below the soft key F9) and press:

> RECALL MORE → RECALL MATH

Verify that the prompt at the top of the screen shows "RECALL MATH = PHZLAG.MTH" and then press:

> ENTER

Press **Disp Format** key to turn on the trace display. Press:

> **Active Trace** → D
> **Trace Coord** → MORE CHOICES → IMAGINARY PART

The display should appear as in Fig. 3.8. The real and imaginary values are 866.6 µ inch Pk and -j 500 µ inch Pk.

Press:

> **Disp Format** → SINGLE
> **Trace Coord** → PHASE

and note the angle readout for order 1 is -30° on the ±180° phase scale.

**Fig. 3.8
The real and imaginary values for a vector of length 1 ∠-30° on the ±180° phase scale.**

```
Disp Frmat


C: D8 FFT(TIME1)      X:1      Order              Y:866.667 uinchpk
          1
    minchpk

  Real
       200
    uinchpk
      /div


        -1
    minchpk
          0Order                                            40Order
D: D8 FFT(TIME1)      X:1      Order              Y:-500   uinchpk
          1
    minchpk

  Imag
       200
    uinchpk
      /div

        -1
    minchpk
          0Order                                            40Order
```
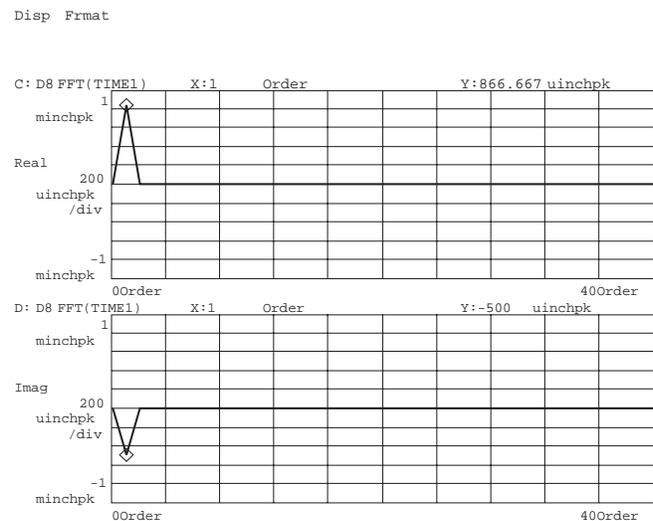
Next we will put a Nyquist Diagram on trace C.

> **Active Trace** → C
> **Trace Coord** → MORE CHOICES → NYQUIST DIAGRAM
> **Scale** → TOP REFERENCE → **1** → BOTTOM → **-1** → milli EXP -3

Note that Real = 866.6 µ inch Pk and Imaginary = - 500 µ inch Pk.

We can display this vector in a polar diagram. Press:

> **Trace Coord** → MORE CHOICES → POLAR DIAGRAM
> **Scale** → Y PER DIV DECADES → **0.2** → milli EXP -3

Note that the vector magnitude is M:1.0005 m inch Pk and the phase is 330°.

Next, press

> **Active Trace** → A

The A trace contains the sine wave of one mil Pk that was Fourier Trans-formed to produce all the spectral results used up to this point.

Press:

> **Marker** → MARKER TO PEAK

and note that the peak value of the sine wave is at 82.031 m Rev. and the magnitude is 1.00058 m inch Pk.

The angular location of the high spot for a sine wave peak at this location would lag the peak by 30°. The phase lag calculation:
$\phi = 0.082031 \times 360° = 29.53°$ (30°). The results should appear as in Fig. 3.7.

Make the D trace active, press:

> **Active Trace** → D
> **Trace Coord** → PHASE

and note that the angle is -30° on the ±180° scale. Press:

> **Analys** → DEFINE FUNCTION

and note that the MATH FUNCTION F1 = Conj (D8). Next, press:

> **Meas Data** → MORE CHOICES → MATH FUNCTION → F1
> **Trace Coord** → PHASE

Note that the phase readout is now 30° on the ±180° scale. Change to the 0 to 360° scale by pressing:

> **Scale** → CENTER REFERENCE → **180** → ENTER

Note that the phase readout is still 30° on the 0° to 360° phase scale.

Next, press:

> **Meas Data** → MORE CHOICES → DATA REGISTER → D8

We are now looking at data which has not been conjugate multiplied and is displayed on a 0 to 360° phase scale. Note that the phase now reads 330° for order 1. Press:

> **Scale** → CENTER REFERENCE → **0** → ENTER

and note that the scale is back to ±180° and the angle is still shown as -30°.

The previous steps showed in a brief fashion how to use conjugate math to implement phase lag scaling. The next few steps require 35670A Firmware revision A.00.24 or higher.

Press:

> **Disp Format** → UPPER/LOWER → MORE → PHASE LAG ON OFF → ON

Note that the D trace phase scale changes to 0° bottom 360° top and order 1 shows an angle of +30°. The vertical axis is now labeled Phase Lag. The C trace is now labeled Polar Lag and shows +30°.

Press:

> **Active Trace** → AB.

Note that the sine wave peak and the phase of the first order in the lower trace are in agreement.

The phase lag convention can be implemented either with the math function conjugate multiply, or by using the phase lag display format function on the 35670A.

At this point, the relationship between the sine wave and the phase lag scaling has been illustrated. The measurement setup for obtaining accurate phase values from a DSA requires a once-per-revolution trigger keyphasor and a vibration signal. In the Order Analysis measurement mode, the once-per-revolution keyphasor is connected to the TACH INPUT and to the EXT. TRIGGER INPUT. The DSA resamples a block of vibration signal data at uniform incre-mental angles of rotation. The trigger point should be set up to trigger on the leading edge of the keyphasor. The first data point in the data block (angle 0) starts at the trigger point.

Section 4
# Slow Roll Removal From Order Records

Eddy current proximity probes are widely used vibration sensors found on critical process machine assets. The probes sense the gap between the probe tip and the rotating surface of a shaft by inducing an eddy current in the conductive surface of the shaft. The probes ideally would produce a signal caused only by the dynamic motion of the surface passing under the probe tip. However, these transducers produce signals caused by shaft surface conductivity variations as well as those caused by shaft dynamics. The dynamic signals of interest can be distorted or lost in the signals caused by the "bumps" on the shaft. These unwanted shaft-related gap signals can come from several sources. The largest signal is usually due to the shaft center of rotation being offset from the shaft center. Other contributors include normal machining imperfections such as out of round, tool chatter marks, etc. These can produce rather large variations in eddy current. Other sources of unwanted signals are variations in shaft plating thickness, hardness variations and surface cracks and scratches. Damage due to mishandling during repair can produce signals that make before-and-after repair comparisons difficult. The American Petroleum Institute considers 0.25 mils peak-peak or less radial runout to be acceptable. In general, the measured dynamic signal should be 20 or more times larger than the shaft surface-related signals for measurement errors and distortion to be at acceptable levels (Fig. 4.1). Distortion of 5% or less in the order

histories and orbits are barely visible (Fig. 4.2). This 20:1 signal-to-noise margin cannot always be met. To correct for these errors, a technique known as slow-roll removal has evolved.

Slow roll removal was first implemented using a DVF by subtracting offsets within the meter. The slow roll removal process started with the

capture of 100 or more gap vectors for one revolution at a low speed with a DVF. Since the vectors are acquired at uniform angular increments, the slow roll could then be subtracted out of all order records captured at higher RPM. The DVF's tunable tracking filters would be set up to remove the first order slow roll from the unfiltered order records. The slow roll was difficult to remove

Fig. 4.1
Two order data records, one with ±20% slow roll noise added, are superimposed. Two order data records are superimposed. One is an ideal record, the second one has 20% slow roll noise added. This is an unacceptable amount of noise.
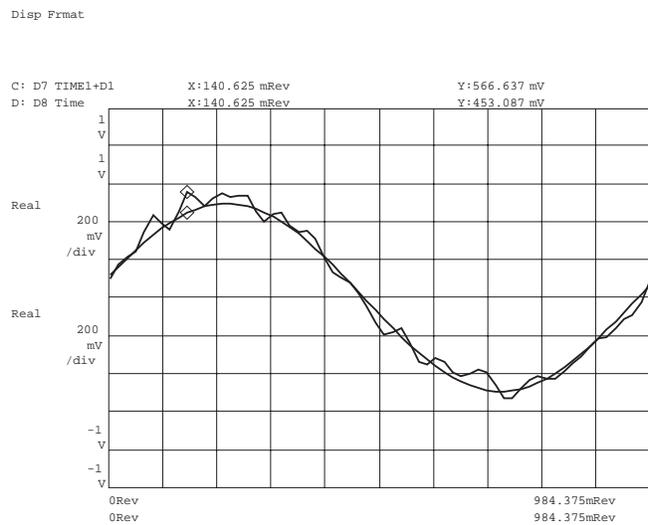
Fig. 4.2
An ideal first order data record superimposed with one having ±5% noise added. An ideal order data record and one having a low 5% noise are superimposed. This is representative of the maximum acceptable noise level.
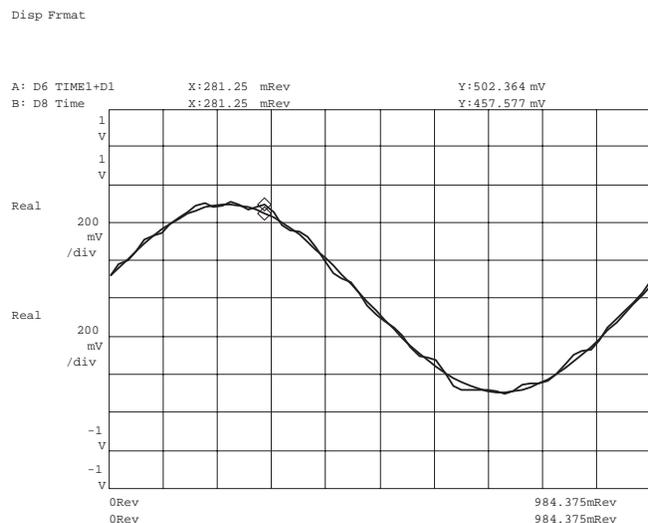
for higher orders. The process was time consuming and tedious so it was usually done "off line" using tape-recorded data.

The waveform math capabilities of the Agilent DSA make slow roll removal much easier. The DSA Order Analysis measurement mode is first set up with an order resolution of one order. Under these conditions the DSA displays exactly one revolution per record (Fig. 4.3). Typically, a measurement with one average at a low RPM is set up, and the X and Y slow roll signal records are measured and then saved in data buffers. Using math functions it is easy to subtract the slow roll order record from all higher RPM order data records in the data capture buffer. The simple math function for the 35670A is shown.

$$F1 = (TIME1 - D1)$$
$$F2 = (TIME2 - D2)$$

In this example Data registers D1 and D2 contain the slow roll records of the X and Y proximity probes. Times 1 and 2 are the order data records from channels 1 and 2. The slow roll measured by the 35670A can include from 0.025 to 200 orders that are user selectable. The slow roll removal and display of live corrected order records as they are measured is a one-step operation (Fig. 4.4 and 4.5). The example at the end of this section provides the step-by-step procedures for slow roll removal using the 35670A. This example uses 300 RPM on a rotor kit. Your slow roll RPM may be different.

Fig. 4.3
The slow roll X-Y data records measured at 300 RPM. These changes in gap distance are static (Not related to speed)
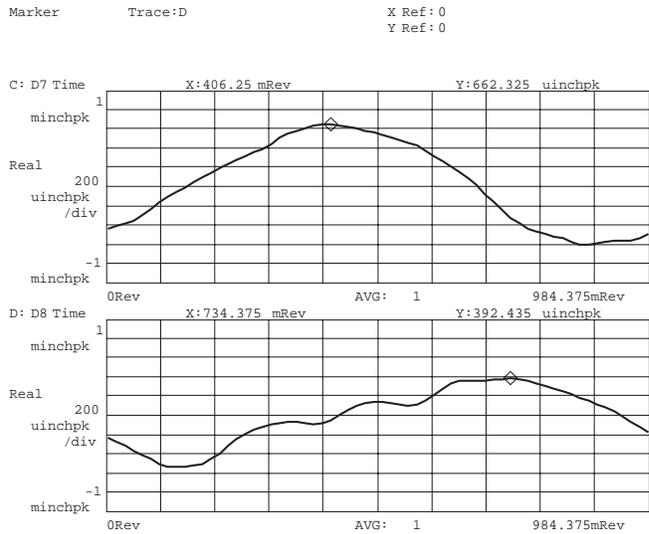
Fig. 4.4
The X probe order records of uncorrected and slow roll corrected data overlaid at 6000 RPM. Removing the static values shows the dynamic behavior.
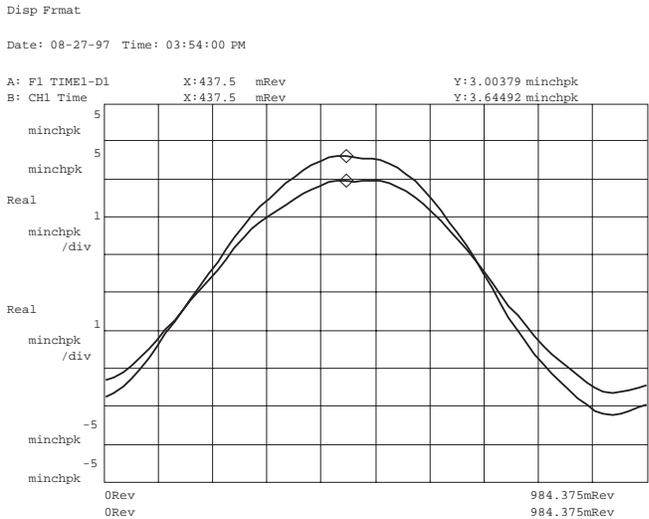
Fig. 4.5
The Y probe order records of uncorrected and slow roll corrected data overlaid at 6000 RPM. Removing the static values shows the dynamic behavior
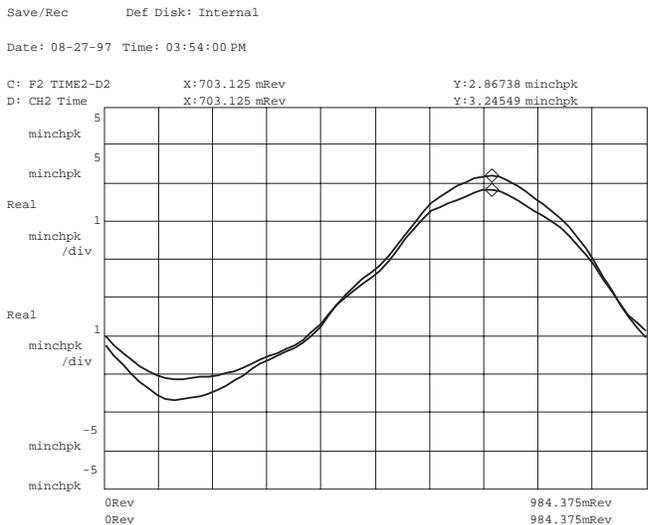
Example: Slow Roll Removal from Order Records

Slow roll removal from order records has three conceptual steps. First, the slow roll behavior must be measured. In our example you will extract this from stored rotor kit run-up data. Next the math functions which subtract the slow roll characteristics from live measurements must be defined. In our example you will recall measurement state parameters to set these functions up. Finally, the actual high speed rotor measurements are made and the corrected results displayed.

In our supplied example data the slow roll measurements are made at 300 RPM. The slow roll measurement takes advantage of averaging in the analyzer. For the actual dynamic shaft measurements it is important to note that the rotor kit used for this data has very little dynamic response below 3000 RPM. You'll be instructed to turn off averaging and to manually change the start speed to 3000 RPM and the stop speed to 8000 RPM. By triggering the measurement on larger RPM increments (increasing the RPM step size) you can speed up the measurement. RPM step arming will be used to allow you to control the exact trigger conditions of each measurement.

The example, using the supplied capture data, is intended to be a guide for your use. You would use similar techniques to make measurements from tape recorded data, rotor kits or directly from probes on an operating machine.

Recalling the Data, State, and Math

The slow roll removal example starts by doing a preset. Press:

Preset → DO PRESET

The runup data, measurement state and math functions are recalled next. Insert the disk "Agilent 35670A Rotor DynamicsMeasurements Techniques" into the analyzer.
Press:

Save / Recall → CATALOG ON / OFF → ON

Rotate the marker knob to highlight the file name "RNUPAC.TIM".
Press:

RECALL DATA → RECALL CAPTURE.

Verify that the prompt at the top of the analyzer screen shows "RECALL CAPTURE =RNUPAC.TIM". Press:

ENTER

Recalling the time capture file will require about one minute.

Rotate the marker knob to highlight the file "SLOROL.MTH" and then press:

Rtn
RECALL MORE
RECALL MATH

Verify that the prompt at the top of the analyzer screen shows "RECALL MATH = SLOROL.MTH". Press:

ENTER

Rotate the marker knob to highlight the file "SLORL1.STA". Press:

Rtn
RECALL STATE

Verify that the prompt at the top of the analyzer screen shows "RECALL STATE = SLORL1.STA". Press:

ENTER
Disp Format
Start

The DSA will begin a measurement on the captured rotor data you just recalled. The tach readout at the top of the screen will increment up to approximately 300 RPM and the X and Y slow roll proximity probe waveforms will appear in the A and B traces with the markers on their respective peaks. The screen should match the data in Fig. 4.3. This is your measurement of slow roll properties.

The next step is to store the slow roll properties for use in correcting dynamic measurements. The X-Y slow roll data will be saved in data registers D1 and D2. Press:

Active Trace → A → **Save Recall** →
SAVE DATA → SAVE TRACE → INTO D1
Active Trace → B → SAVE TRACE →
INTO D2

Modifying the Measurement State

The order analysis state will now be modified to measure from 3000 to 8000 RPM. The data display will be set up to show the results of the uncorrected order data overlaid with the slow roll corrected data.
Press:

    Avg → AVERAGE ON OFF → OFF

The measurement will be set to start at 3000 RPM and to stop at 8000 RPM. The RPM step size will be increased to 40 RPM to speed up the measurement.

    Freq → MIN RPM → 3000→ RPM →
    MAX RPM → 8 → KRPM
    Trigger → ARM SETUP → RPM STEP ARM
    → RPM STEP SIZE → **40** → RPM

The display is set up to display the math function results. Press:

    Active Trace → A
    Meas Data → MORE CHOICES →
    MATH FUNCTION → F1
    Active Trace → B → F2
    Active Trace → A B
    Trace Coord → MORE CHOICES → REAL PART
    Start

to begin the measurement. The tach display will start incrementing up and when it reaches 3000 RPM, the slow roll corrected data will appear on the screen. The slow roll correction will continue to update every 40 RPM and stop at approximately 8000 RPM. The last measurement at 8000 RPM will appear fixed on the screen.

Display Trace Setup

The following key sequence sets up the display so that the slow roll corrected and raw data can be compared. The trace setup to display uncorrected X probe data in the B trace is as follows:
Press:

    Disp Format → QUAD
    Active Trace → B
    Meas Data → TIME CHAN 1

Trace setup to display the slow roll corrected data for the Y probe in trace C is:

    Active Trace → C
    Meas Data → MORE CHOICES →
    MATH FUNCTION → F2

Trace setup to display uncorrected Y-probe data in trace D is:

    Active Trace → D
    Meas Data → CHAN 1 2 3 4 → **2** →
    TIME CHAN 2

All four traces will be set to display coordinates Real versus 1 rotation and to autoscale their data.

    Active Trace → A B C D
    Trace Coord → MORE CHOICES → REAL PART
    Scale → AUTO SCALE ON OFF → ON →
    OFF

Turning autoscale on, then off, forces a one time rescaling of the display.

Next set up a front back (overlaid) display of the slow roll corrected and uncorrected X data. The X probe data will be in traces A and B, the Y probe data will be in traces C and D.

    Active Trace → A B
    Marker → COUPLED ON OFF → ON →
    MARKER TO PEAK
    COUPLED ON OFF → OFF
    Active Trace → C D →
    MARKER TO PEAK
    Disp Format → SINGLE FRNT/BACK
    Active Trace → A B

This displays the corrected and uncorrected X probe data. Note that the slow roll corrected X probe data trace is about 0.64 mils less than the uncorrected X order data record (Fig. 4.4).

The Y probe uncorrected and corrected data are examined by making the C trace active.

    Active Trace → C D

The results will be very similar to Fig. 4.5. Note that the slow roll correction is approximately 0.378 mils. The smooth shaft on the rotor kit produced only a small slow roll error. The slow roll correction did not produce significant effects until the dynamic response began to grow at 3000 RPM. The first 10 orders were removed in one pass. Since this approach is not correcting one order at a time as is possible with a DVF, the results you will see are going to be a little different. When a slow roll record is subtracted from a higher RPM record that is only slightly larger, the difference will be dominated by noise.

A detailed step-by-step key sequence is provided as a reference in Appendix A.

Section 5
Slow Roll Removal From Orbits

Orbits, or X versus Y displays of shaft position change versus angle of rotation, were first measured by placing a needle point on a turbine shaft end and then observing the motion with a microscope. This discovery from the 1930's was replaced long ago by pairs of proximity probes, Digital Vector Filters and an oscilloscope. (Figure 5.1)

Orbit displays give a two dimensional visual picture of the motion of a rotating shaft. Just like order measurements, orbits can be contaminated by shaft related "noise." Removing the noise using slow roll compensation techniques greatly improves the quality of orbit data. The advantages of slow roll correction were covered in Section 4 of this note.

The 35670A has built-in orbit displays, but these are limited to raw time or order data records. The standard orbit display can not be used to show slow roll corrected orbits. Fortunately, the Agilent DSA has another display type which can be used to show an orbit, the Nyquist Diagram. The Nyquist Diagram displays real versus imaginary data, so we must go through two simple steps to get a slow roll corrected orbit. First, we must calculate the slow roll corrected data. Second, we

must multiply the corrected Y data by the complex number (0+1j) to put it on the Nyquist diagram imaginary axis. The imaginary axis (Y) probe is +90° from the real axis (X). Thus the two displays are equivalent representations.

The math function is as follows:
$$F3 = (TIME1 - D1) + K4 * (TIME2 - D2)$$

The slow roll X and Y data are saved in data registers D1 and D2. K4 is the complex constant (0 + j1). Times 1 and 2 are the live order records. Multiplying the corrected Y data by (0 + j1) converts the Y data record from real values to imaginary values. Then the X real data are added to the Y imaginary data to produce one record of the combined corrected X-Y order. The last step is to set up a Nyquist (or polar diagram) to display the results of the math function F3 (Fig. 5.2).

Fig. 5.1
A block diagram of a typical DVF set up to measure and display an orbit.
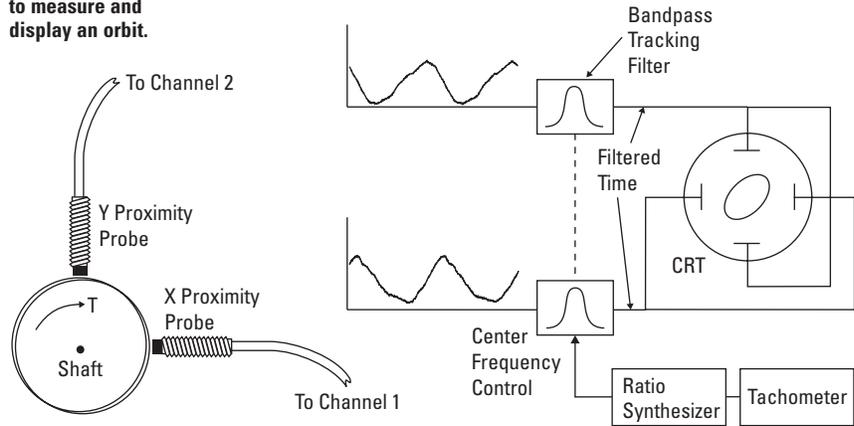
Fig. 5.2
A corrected orbit displayed using the Nyquist trace coordinates in the Agilent 35670A.
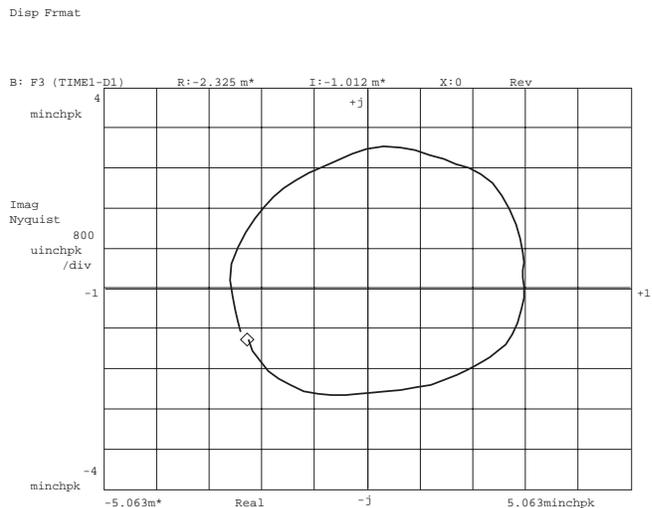
Example: Slow Roll Removal From Orbits

The example of slow roll removal from orbits uses the math and time capture files from the example in Section 4 above. The X-Y order records are combined into one data record for display. The standard orbit display is selected with the ORBIT 2/1 under the **Meas Data** key. The orbit display works with time records in the FFT mode or order records in the order analysis mode. To display slow roll corrected orbits, we make use of a math function to combine the X-Y data and use the Nyquist Diagram display coordinates to view the results. As in the last example, the X-Y slow roll is measured at 300 RPM and saved in data registers D1 and D2. The math function takes the current order record for each probe and subtracts the slow roll correction. The Y axis data is multiplied by $(0 + 1j)$ to move it to the imaginary axis. The X and Y data are then combined to make a complex number (real + imaginary) pair.

Verify Data Setup

If the DSA has not been powered down since the completion of the example in Section 4, then the time capture and math files should still be in memory. You can check by viewing the time capture buffer and the analysis portion of the 35670A. To display the time capture buffer, press:

> **Active** → AB → **Meas Data** →
> ALL CHANNELS → CAPTURE CHANNEL*
> **Disp Format** → UPPER/LOWER → **Scale** →
> AUTOSCALE ON OFF → ON → OFF

If the runup data do not appear on the screen, then the time capture, state, and math records of the Section 4 example will need to be recalled. To verify the math, press:

> **Analys** → DEFINE FUNCTION

and compare F3 in the DSA to:

$$F3 = (TIME1 - D1) + K4*(TIME2 - D2)$$
$$K4 = 0.0000 + j$$

1.0000

Next, verify that data registers D1 and D2 contain the slow roll data. Press:

> **Meas Data** → MORE CHOICES →
> DATA REGISTERS → D1 →
> **Active Trace** → B → D2

The display will be the same as (Fig. 5.3).

If the data and math are still in the 35670A memory, proceed to the section titled "Recall Measurement State SLORL2.STA." You can check the time buffer contents by pressing:

> **Active Trace** → AB
> **Meas Data** → ALL CHANNELS →
> MORE CHOICES → TIME CAPTURE*
> **Scale**
> AUTOSCALE ON/OFF → ON → OFF

If no time capture data appears on the traces, you will need to reload the file.

Fig. 5.3
The X and Y slow roll records in data registers D1 and D2.

Recalling Data

Insert the disk "Agilent 35670A Rotor Dynamics Measurements Techniques" into the analyzer.
Press:

> **Save / Recall** → CATALOG ON / OFF → ON

Rotate the marker knob to highlight the file name "RNUPAC.TIM".
Press:

> RECALL DATA → RECALL CAPTURE.

Verify that the prompt at the top of the analyzer screen shows "RECALL CAPTURE =RNUPAC.TIM".
Press:

> ENTER

Recalling the time capture file will require about one minute.

Rotate the marker knob to highlight the file "SLOROL.MTH" and then press:

> **Rtn**
> RECALL MORE
> RECALL MATH

Verify that the prompt at the top of the analyzer screen shows "RECALL MATH = SLOROL.MTH".
Press:

> ENTER

Rotate the marker knob to highlight the file "SLORL1.STA".
Press:

> **Rtn**
> RECALL STATE

Verify that the prompt at the top of the analyzer screen shows "RECALL STATE = SLORL1.STA".
Press:

> ENTER
> **Disp Format**
> **Start**

The tach readout at the top of the screen will increment up to approximately 300 RPM and the X and Y slow roll proximity probes waveforms will appear in the A and B traces with the markers on their respective peaks.

Now save the X-Y slow roll data in registers D1 and D2.
Press:

> **Active Trace** → A
> **Save Recall** → SAVE DATA →
> SAVE TRACE → INTO D1
> **Active Trace** → B
> SAVE TRACE → INTO D2

Recall Measurement State SLORL2.STA

Press:

> **Save/Recall** → CATALOG ON OFF → ON

and rotate the marker knob to highlight the file "SLORL2.STA". Press:

> RECALL STATE

and verify "RECALL STATE = SLORL2.STA," and then press:

> ENTER
> **Disp Format**
> **Start**
> **Scale** → AUTOSCALE → ON / OFF → ON

The tach display will begin to increment up. At about 3000 RPM two orbits will become obvious on the display. The slow roll corrected orbit is the inner one, and the outer orbit is the raw X versus Y data. The marker was set at 0.00 revolutions, which corresponds with the phasor leading edge, and the record length is 0.984375 revolutions. The combination of the markers at 0 revolutions and the record length being about 1.5% short of a full revolution provides the bright spot, blank spot that is similar to the one provided by a DVF. However, the marker must be set at 0 revolutions and not moved while the orbits are being displayed. The last orbit should appear near 6000 RPM and will look like (Fig. 5.4).

Press:

>   **Scale** → AUTOSCALE → ON / OFF → OFF
>   **Disp Format** → UPPER LOWER

This separates the overlaid traces. The upper trace is the default orbit 2/1 display and the lower trace is the slow roll corrected orbit displayed in a Nyquist Diagram.

Next, the slow roll corrected X -Y order records will be viewed. Press:

>   **Active Trace** → CD
>   **Marker** → MARKER TO PEAK

The upper trace is the corrected X probe data ,the Real part, and the lower trace is the corrected Y probe data, the Imaginary part, from the math function F3 (Fig. 5.5).

Next, we will increase the test speed range to start at 5000 RPM and end at 8000 RPM. Press:
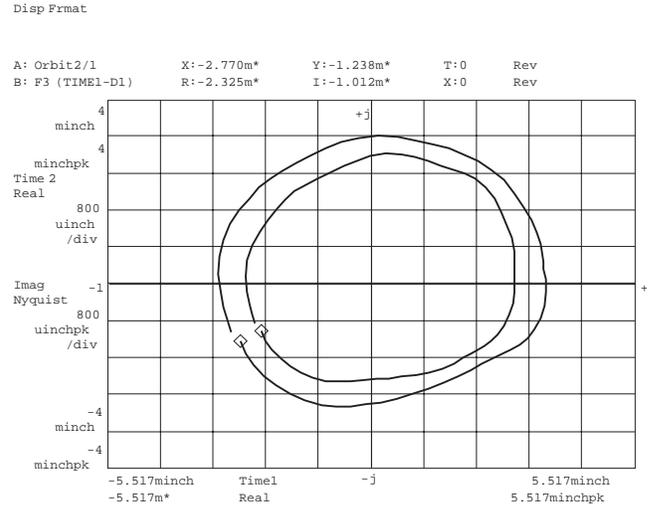
>   **Freq** → MIN RPM → **5** → KRPM →
>   MAX RPM → **8** → KRPM
>   **Active Trace** → AB
>   **Disp Format** → SINGLE FRONT/BACK
>   **Scale** → TOP REFERENCE
>   **5** → BOTTOM → **-5** → MILLI-EXP-3
>   **Start**

The tach display will indicate a run-up is in progress. At 5000 RPM, the first orbits will appear and will continue to update until 8000 RPM is reached. The 35670A can display two live orbits and two slow roll corrected orbits with the optional four analog inputs.
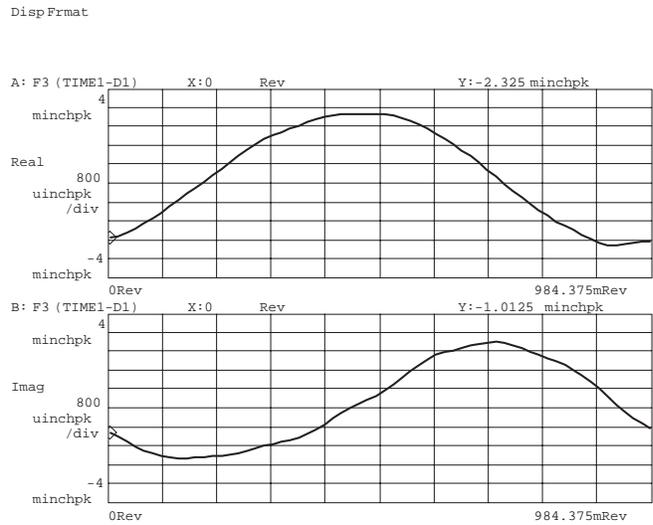
Manual Setup

The manual setup of the Measurement State for this example is a small extension of the example in Section 4. Refer to Appendix A for the detailed setup key sequences.

Fig. 5.4
The slow roll corrected orbit is the inner orbit. The outer orbit is the uncorrected X versus Y data. The combination of the markers at 0 revolutions and showing 98% of a full revolution provides the bright spot, blank spot that will be familiar to DVF users.


```
Disp Frmat

A: Orbit2/1        X:-2.770m*      Y:-1.238m*      T:0       Rev
B: F3 (TIME1-D1)   R:-2.325m*      I:-1.012m*      X:0       Rev
          4
       minch                               +j
          4
     minchpk
Time 2
 Real
        800
       uinch
        /div

 Imag     -1                                                        +
Nyquist
        800
     uinchpk
        /div

         -4
       minch
         -4
     minchpk
          -5.517minch     Time1        -j        5.517minch
          -5.517m*        Real                   5.517minchpk
```

Fig. 5.5
Order records for the X and Y probes. These are calculated by math function F3 and are viewed by displaying the real part, for the X data and the imaginary part for the Y data.


```
Disp Frmat

A: F3 (TIME1-D1)      X:0      Rev          Y:-2.325 minchpk
          4
     minchpk

 Real
        800
     uinchpk
        /div

         -4
     minchpk
         0Rev                              984.375mRev

B: F3 (TIME1-D1)      X:0      Rev          Y:-1.0125  minchpk
          4
     minchpk

 Imag
        800
     uinchpk
        /div

         -4
     minchpk
         0Rev                              984.375mRev
```
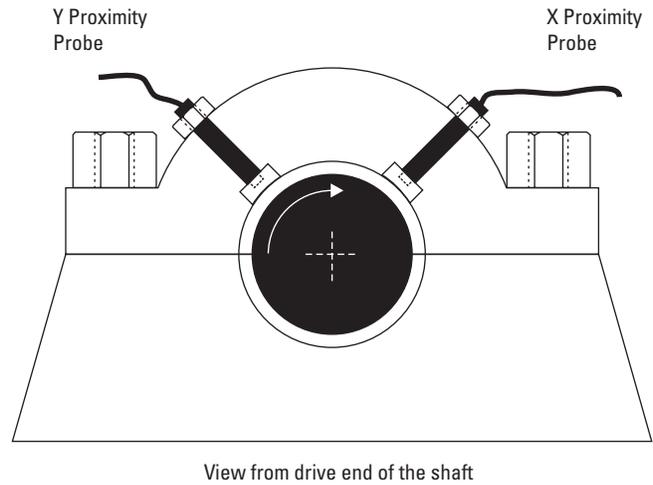
Section 6
Orbit Rotation to Horizontal and Vertical

Proximity probes cannot easily be mounted in the desired horizontal and vertical orientation due to bearing split lines and interference of oil lines, etc. As a result, X-Y probe pairs are often encountered that are rotated from the ideal horizontal and vertical position (Fig. 6.1). The probe pair in Fig. 6.1 is rotated +45° from true horizontal and vertical. On many machinery trains, several different probe pair orientations may be encountered (Fig. 6.2). If you want to compare orbits along a machinery train with different probe orientations, you must rotate the orbits back to a common horizontal and vertical position. The rotation correction is very critical when the measurement results are to be communicated clearly to others and when multi-plane balancing is done.
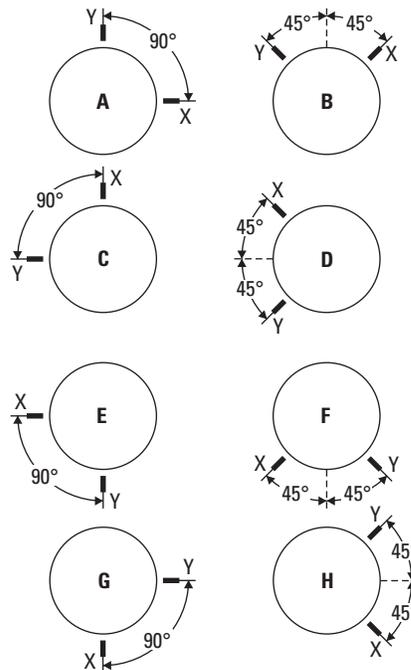
The default orbit displays and Nyquist Diagram trace coordinates in the 35670A assume the measured and slow roll corrected data that go into orbits are from probes that are oriented in horizontal and vertical positions. For the data in this note Channels 1 and 3 measure from the X probes (horizontal orientation) and channels 2 and 4 measure from the Y probes (vertical orientation).

The orbit and Nyquist Diagram trace coordinates cannot be rotated to correct for proximity probe pairs that are rotated from true horizontal and vertical. However, the trace coordinate polar diagram is easily rotated using the POLAR ROTATE function.

Fig. 6.1
Proximity probes are seldom mounted on machines in the ideal horizontal and vertical orientation. The probe pair shown are rotated +45° from horizontal and vertical.

View from drive end of the shaft

Fig. 6.2
Radial proximity probe pair angular locations and identification commonly found on machinery*.

If data were acquired from a probe pair like those in Fig. 6.1, the resulting orbit would be rotated +45° from true horizontal and vertical. The correction would require a rotation of the orbit data by -45° (Fig. 6.3).

Example: Orbit Rotation

If the time capture data is still in memory, it is not necessary to recall it again. You can use the technique in Section 5 (Pg. 21) to display the time buffer. Otherwise you will need to recall the file again.

Recalling Data

Insert the disk "Agilent 35670A Rotor Dynamics MeasurementsTechniques" into the analyzer.

Press:

Save / Recall → CATALOG ON / OFF → ON

Rotate the marker knob to highlight the file name "RNUPAC.TIM".
Press:

RECALL DATA → RECALL CAPTURE.

Verify that the prompt at the top of the analyzer screen shows "RECALL CAPTURE =RNUPAC.TIM".
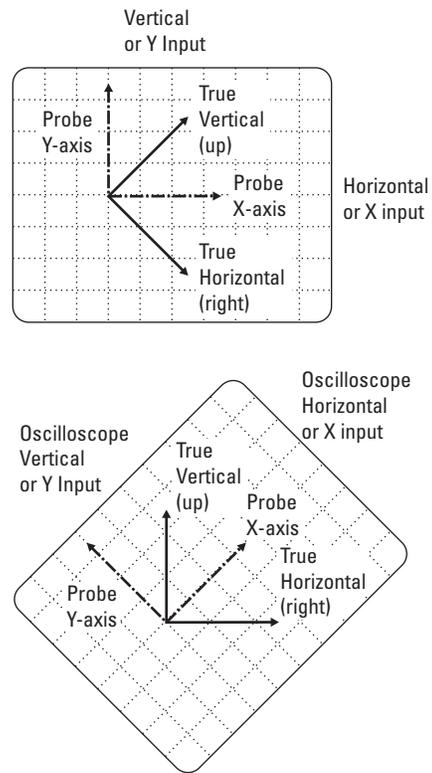Press:

ENTER

Recalling the time capture file will require about one minute.

Rotate the marker knob to highlight the file "SLORL1.STA".
Press:

RECALL STATE

Fig. 6.3
The angular transducer positions are rotated relative to the display coordinates as shown. The correction is made by rotating the display +45° or rotating the data -45° as in this case*.

Vertical or Y Input

Probe Y-axis

True Vertical (up)

Probe X-axis

Horizontal or X input

True Horizontal (right)

Oscilloscope Horizontal or X input

Oscilloscope Vertical or Y Input

True Vertical (up)

Probe X-axis

True Horizontal (right)

Probe Y-axis

* Figure courtesy of *Machinery Malfunction Diagnosis and Correction, Vibration Analysis and Troubleshooting for the Process Industries*, Robert Eisenmann Sr. P.E. & Robert Eisenmann Jr. PTR Prentice Hall, Nov. 97. , chapter 6

Verify that the prompt at the top of the analyzer screen shows "RECALL STATE = SLORL1.STA". Press:

ENTER
Disp Format
Start

The tach readout will increment up to approximately 300 RPM and the X and Y slow roll proximity probe waveforms will appear in the A and B traces with the markers on their respective peaks.

Set up an orbit display by pressing:

Disp Format → SINGLE
Meas Data → ORBIT 2/1
Marker → MARKER ON/OFF → ON →
COUPLED ON/OFF → ON →
MARKER X ENTRY → **0 Rev.**

Your display should now look like Fig. 6.4. Now press:

Active Trace → B
Meas Data → ORBIT 2/1
Trace Coord →MORE CHOICES →
POLAR DIAGRAM
POLAR ROTATION → **-45** → DEGREES

The trace B display should now look like Fig. 6.5. Note that the marker readout on the polar diagram is now a vector magnitude and angle. Selecting POLAR DIAGRAM does a rectangular to polar conversion (magnitude/angle).

Fig. 6.4
A The orbit measured here is assumed to have come from probe pairs positioned rotated +45° horizontal and vertical.
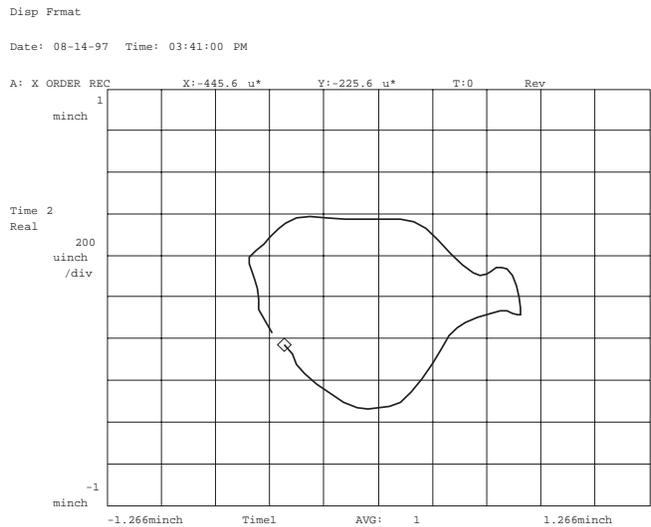
Fig. 6.5
Polar rotation of - 45° was applied to the data in (Fig. 6.4) to re-orient the orbit to true horizontal and vertical coordinates.
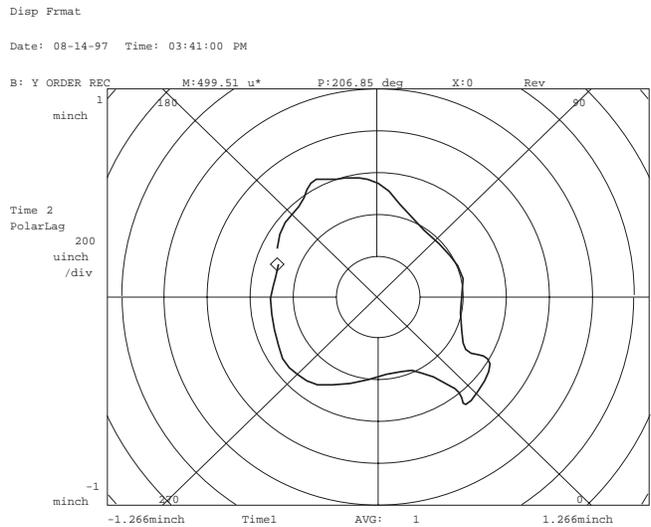
Section 7
Slow Roll Compensation of Bodé Plots

A Bodé plot is a graph of magnitude and phase versus speed or frequency. In rotor dynamics a Bodé plot usually graphs the magnitude and phase of a specific order versus RPM (Fig 7.1) The Bodé plot is used to help identify rotor critical speeds and to examine rotor dynamics on an order by order basis. Shaft measurement anomalies can obscure and mask the dynamic behavior of order track measurements just as they do with orbits. Slow roll compensation of Bodé plots evolved to enhance the results by removing the slow roll errors so that only the dynamic response was displayed. Slow roll compensation is done by subtracting out the slow roll vector from the Bodé plot over the speed range of the measurement.

In the example at end of this section, a first order Bodé plot is extracted from a 300 to 8000 RPM runup. The marker is used to enumerate the Real and Imaginary values of the slow roll vectors at 300 RPM. Values are entered into the math constants K1 and K2 for X-Y probe data. The slow roll vector is subtracted from all subsequent RPM points using the math functions.

$$F1 = (track\ 11 - K1)$$
$$F2 = (track\ 12 - K2)$$

The 35670A can measure magnitude and phase versus RPM on five orders simultaneously, and can have four input channels on line at one time. Slow roll compensation can be applied to the Bodé plot data as the machine is tracking the speed ramp-up or the compensation can be applied after the Bodé plot is completed. In the example, the compensation is applied after the
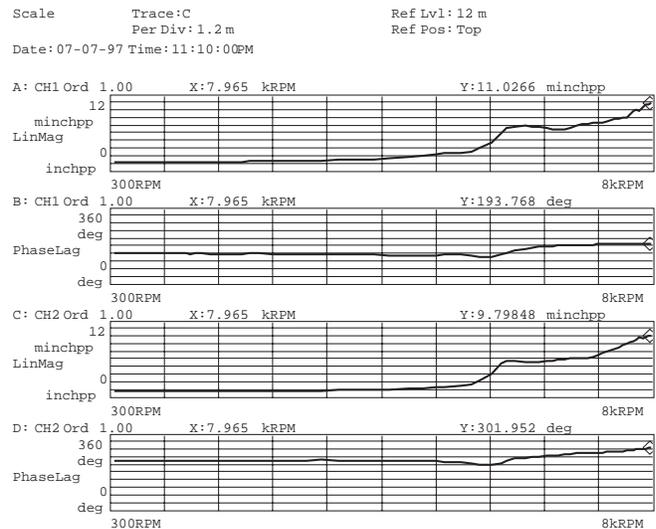
Bodé plot is completed. The slow roll compensated Bodé plot of Fig. 7.2 results from displaying the math function and selecting the Phase Lag scale.

Example: Slow Roll Compensation of Bodé Plots

The compensation of a Bodé plot begins with measuring the slow roll vector. The vector is subtracted from all higher RPM vectors. The slow roll compensation can be applied as the machine is ramping up in speed or after the startup transient has been captured. In this example, the compensation is applied to an order track extracted from a runup transient that was throughput to the time capture buffer. The example exercise walks you through compensating the first order. The 35670A measures four additional orders that you may wish to compensate. The example begins with recalling a time capture file, a

Fig. 7.1
A first order Bodé plot from a rotor kit. Magnitude and phase versus RPM were extracted from a run-up capture. The trace coordinates were set up by selecting magnitude pk-pk on the A and C traces and phase lag on the B and D traces.

Fig. 7.2
The compensated Bodé plot of Fig. 7.1 was slow roll compensated over the speed range of 300 to 6000 RPM by a slow roll vector measured at 300 RPM.

27
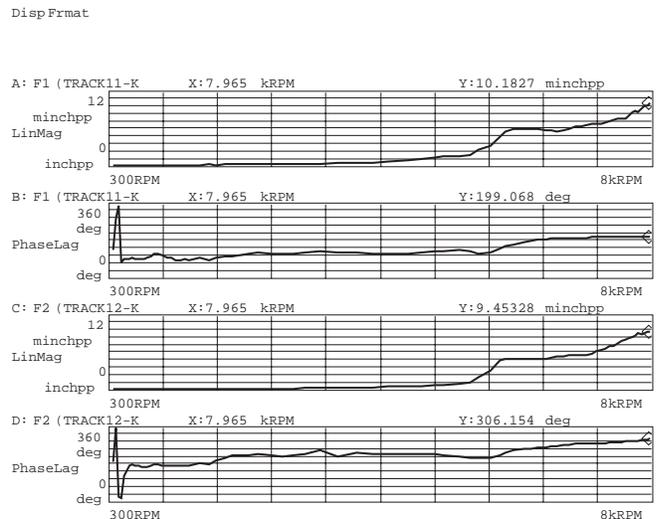
measurement state, and a math function. You are walked through the steps to measure, extract, and enter the slow roll vector into the math constants and view the compensated results. Next, the display is set up manually to compare the measured and compensated Bodé plots.

Recalling the Setup

Note: If the time capture data is still in memory, it is not necessary to recall it again. You can use the technique in Section 5 (Pg. 21) to check the contents of the time buffer. You will need to recall the state and math files for this section.

Insert the disk "Agilent 35670A Rotor Dynamics Measurements Techniques" into the analyzer.
Press:

>   **Save / Recall** → CATALOG ON / OFF -> ON

Rotate the marker knob to highlight the file name "RNUPAC.TIM".
Press:

>   RECALL DATA → RECALL CAPTURE.

Verify that the prompt at the top of the analyzer screen shows "RECALL CAPTURE = RNUPAC.TIM".
Press:

>   ENTER

Recalling the time capture file will require about one minute.

Rotate the marker knob to highlight the file "BODE.STA".
Press:

>   **Rtn**
>   RECALL STATE
>   ENTER

Rotate the marker knob to highlight the file "BODE.MTH" and then press:

>   **Rtn**
>   RECALL MORE
>   RECALL MATH

Verify that the prompt at the top of the analyzer screen shows "RECALL MATH = BODE.MTH". Press:

>   ENTER
>   **Disp Format**
>   **Start**

to measure the Bodé plots for orders 1 through 5 on the X and Y probes.

As the measurement proceeds, the tracking markers will read out each measurement point on all four traces (Fig. 7.1). The A and C traces are the linear magnitudes in mils PP. The B and D traces are order 1 phase for the X-Y probes.

To view the higher orders that were also measured (orders 2 through 5) press:

>   **Active Trace** → AB
>   **Meas Data** → ALL CHANNELS →
>   MORE CHOICES → ORDER TRK CHAN * →
>   TRACK 2 ORD 2.0 →
>   **Scale** → AUTOSCALE ON OFF → ON

Next select track 3 through track 5 and back to track 1 ORD 1.00 With the A and B traces displaying track 1, press:

>   **Scale** → TOP REFERENCE → **12** →
>   BOTTOM → **0** → milli EXP-3
>   **Marke**r → COUPLED ON OFF → ON →
>   MARKER ENTRY → **300** → RPM
>   **Disp Format** → UPPER LOWER

Both the A and B traces should still be active. Press:

>   **Trace Coord** → MORE CHOICES →
>   NYQUIST DIAGRAM

At the top of each trace, the slow roll Real and Imaginary values at 300 RPM are displayed (Fig. 7.3).

Fig. 7.3
The Nyquist diagram of order 1 of the X-Y probe data provides the easiest way of extracting the Real-Imaginary values for slow roll correction. Note: the marker readout at the top of each trace displays the real and imaginary values directly.
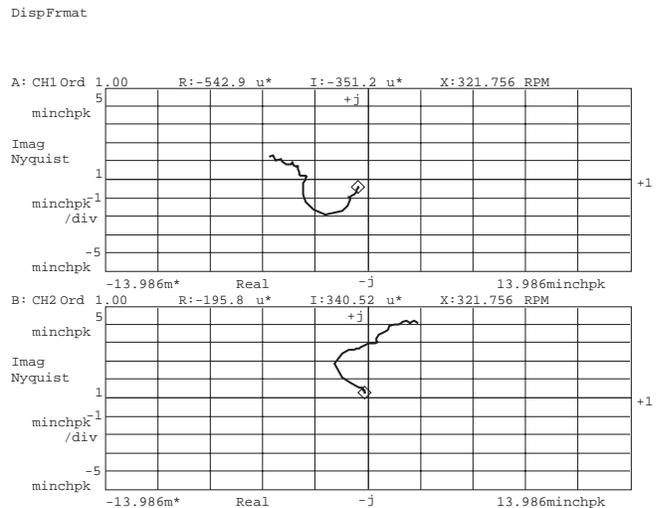
Copy the values in the space provided. (Be sure the marker is at 300 RPM.)

A: CH1 ORD1

R: _____EXP _____

I: _____EXP _____

X: 300 RPM

B: CH2 ORD2

R: _____EXP _____

I: _____EXP _____

X: 300 RPM

The Real and Imaginary values will be entered into the waveform math constants K1 for the X probe and K2 for the first order Y probe data.

F1 = (TRACK11 - K1)

F2 = (TRACK12 - K2)

Press:

> **Analysis** → DEFINE CONSTANT K1-K5 → DEFINE K1 →

Using the numeric keypad enter the real and imaginary numbers.

Real:

> _____ EXP _____ → +J →
> +/− → − →
> _____ EXP __DEFINE K2 →
> ENTER REAL & IMAG. PARTS
> +/− → _____ EXP ____ → +J →
> +/− → _____ EXP ___

Next, the slow roll compensated and uncompensated Y first order data will be overlaid and compared. Make the C trace active by pressing:

> **Active Trace** → C
> **Meas Data** → MORE CHOICES → MATH FUNCTION → F2
> **Active Trace** → CD
> **Trace Coord** → MORE CHOICES → NYQUIST DIAGRAM
> **Disp Format** → SINGLE FRONT BACK
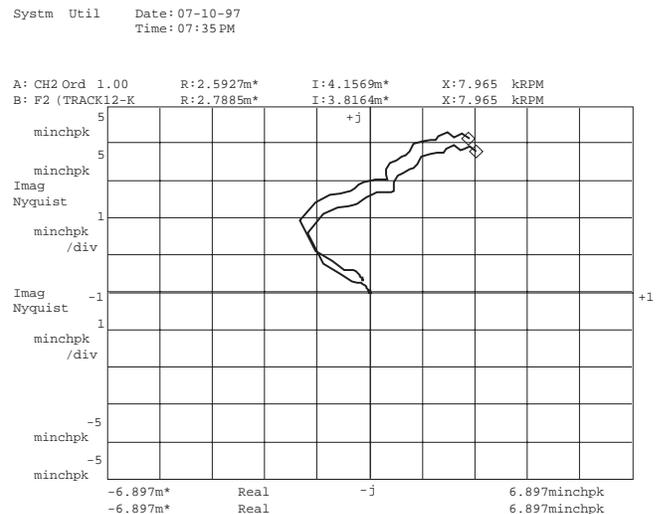> **Scale** → TOP REFERENCE → **5** → BOTTOM → **-1** → milli EXP-3

The coupled markers should still be active and at 300 RPM. The compensated and uncompensated first order Y probe results are overlaid in the Nyquist Diagram. The two Real-Imaginary data pairs at 321 RPM are displayed at the top of the traces. Evaluate the differences in Real-Imaginary values on the traces (Fig. 7.4).
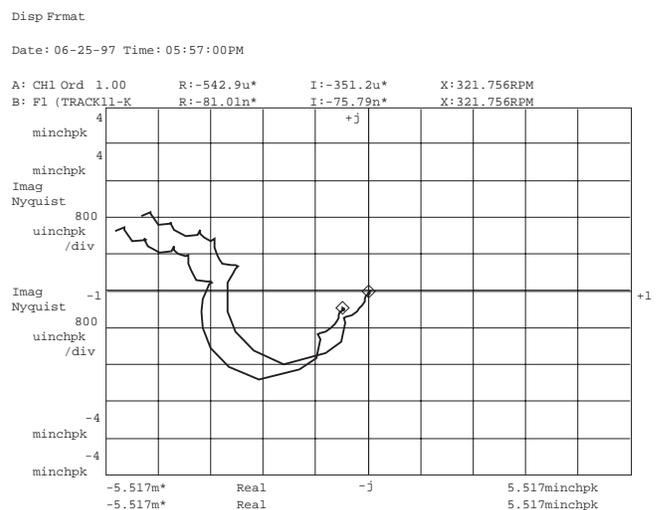
Next, the X probe data will be compared. Press:

> **Active Trace** → B
> **Meas Data** → MORE CHOICES → MATH FUNCTION → F1
> **Active Trace** → AB
> **Trace Coord** → MORE CHOICES → NYQUIST DIAGRAM
> **Display Format** → SINGLE FRONT BACK
> **Scale** → TOP REFERENCE → **4** → BOTTOM → **-4** → MILLI EXP-3

Evaluate the two traces at 300 RPM as in Fig. 7.5.

Fig. 7.4
Nyquist Diagram overlay of first order Y probe data. These show the slow roll compensated and uncompensated data.


```
Systm  Util     Date:07-10-97
                Time:07:35 PM


A: CH2 Ord 1.00     R:2.5927m*      I:4.1569m*      X:7.965  kRPM
B: F2 (TRACK12-K    R:2.7885m*      I:3.8164m*      X:7.965  kRPM
```

Fig. 7.5
Nyquist Diagram overlay of first order X probe data. These show the slowroll compensated and uncompensated data. Note that the subtraction of the slow roll vector has set the Real and Imaginary values at 321 RPM to very near the origin 0.0 + j 0.0.


```
Disp Frmat

Date:06-25-97 Time:05:57:00PM

A: CH1 Ord 1.00     R:-542.9u*     I:-351.2u*     X:321.756RPM
B: F1 (TRACK11-K    R:-81.01n*     I:-75.79n*     X:321.756RPM
```

Compensated Bodé Plot

You have now entered sufficient information to view compensated and uncompensated Bodé plots.

Press:

Freq → MIN RPM → **800** → RPM

This changes the running range of the meaurements.

Note that the subtraction of the slow roll vector has set the Real and Imaginary values at 321 RPM to very near the origin 0.0 + j 0.0. A new measurement start speed of 800 RPM will illustrate how slow roll compensation can correct the order tracks as they are measured. The uncompensated and compensated Bodé plots will be overlaid and compared.

Now, change the display to linear magnitude. Press:

Trace Coord → LINEAR MAGNITUDE → Y UNITS → AMPLITUDE Pk PP RMS → PP
**Scale** → TOP REFERENCE → **12** → BOTTOM → **0** → MILLI EXP-3
Start

The results of (Fig. 7.6) will appear on the screen.

Press:

Trace Coord → PHASE
Scale → CENTER REFERENCE → **180**

Compare the compensated and uncompensated phase of the Bodé plots on the DSA and Fig. 7.7. The slow roll compensation of an order track is done on each order with its unique slow roll vector. For example, using this technique, you could enter the real and imaginary values for the 2nd order. A math function for the 2nd order would be used to display corrected 2nd order magnitude and phase.

Fig 7.6
A Bodé plot overlay of the slow roll compensated and uncompensated magnitude data from the X probe. Note the compensated 1st order magnitude is lower.
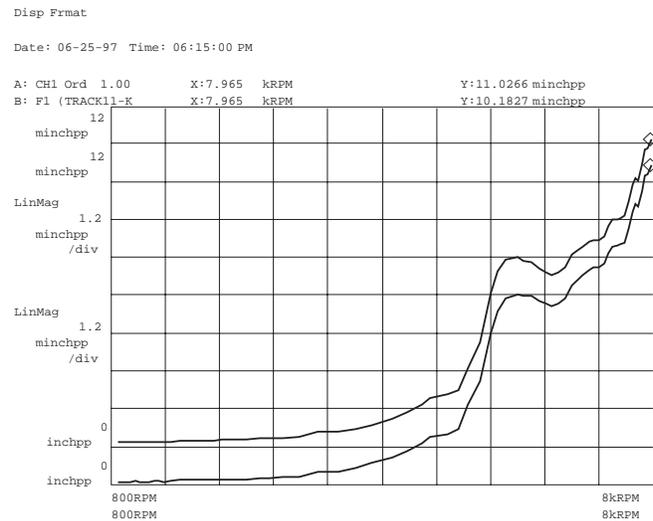
Fig 7.7
A Bodé plot overlay of the slow roll compensated and uncompensated phase data from the X probe.
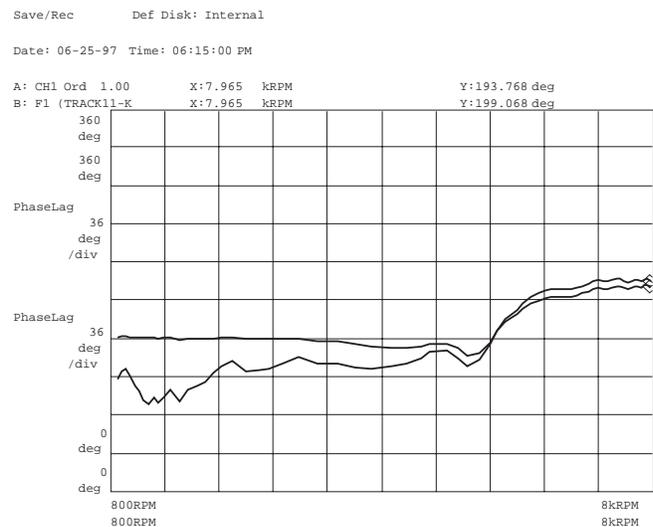
Section 8
Shaft Center Line versus Speed or Time

The measurements of shaft center line position changes are commonly used to investigate shifts in a machine's shaft center of rotation. These may be due to thermal effects, load changes, oil temperature, RPM, preloads, etc. These measurements are used to document a machine's behavior during startup commissioning and to monitor shaft position changes during heat soaks. The DC gap voltages from X-Y proximity probes are sometimes logged along with oil and case temperature, oil pressure and RPM. The data can then be plotted versus time, temperature, and/or RPM to document how the journal positions are related to other machine variables.

The shaft center line measurements are typically done manually, with an integrating digital voltmeter that has 5.5 digits of resolution and an accuracy on that same order. The integrating voltmeter requirement comes from the need to "integrate" out the AC signals, due to the dynamics of the rotor and AC line frequency noise. The raw voltage data are manually entered into a PC spreadsheet where the change in gap can be referenced to the at-rest gap voltages and plotted versus other variables. The proximity probe scale factors are applied to the change in voltage readings. The readings are generally taken on a one- to four-hour time interval so the data can be logged manually. Ideally, shaft

center line position measurements should be acquired on every startup. However, measuring shaft position changes during a fast startup transient requires a high-speed data acquisition instrument. Until recently, these scanning digital integrating voltmeters were expensive and required additional software to get the data to a PC spreadsheet.

The low-cost 34970A Data Logger can automate the measurement of voltage and scaling to engineering units. This data logger can be set up to capture and scale readings of gap voltages, temperatures, and pressures at user-specified time intervals. The scaled gap and other readings are easily transferred to the PC spreadsheet via IEEE 488, or RS232 I/O using the software supplied with the data logger. The 34970A data logger supports a variety of scanned input cards including thermocouple, a counter/time interval card for RPM logging, and four-wire resistance measurements for scaled strain gauge measurements. The data logger can scan at 250 readings per second and hold 50,000 time-stamped readings in its non-volatile memory. Even at 250 readings per second, there are fast startup transients that this unit would have difficulty tracking.

The 35670A DSA measures shaft center line as a standard capability of the computed order tracking option. An order track on order 0 for the X-Y probes is the starting point. The zero order data (DC) contains the mean position values with the higher order vibration signals "integrated" out. The Agilent DSA can extract the center line position change versus RPM on fast runup transients, which can also be done with the data logger approach for moderate speed ramp rates. When the shaft center line needs to be monitored for longer times such as during heat soaks, the DSA measurement arming is changed from RPM increment to time increment. The time increment arming can be set to range from milliseconds to hours. The measured gap values can come directly from the analog inputs or the transient data can be captured and post processed.

The display of the results in Fig. 8.1 A and B are the X-Y probe results. The X-Y data can be combined in Nyquist Diagram or polar coordinates to provide an axial view of the shaft's X-Y position change as a function of RPM (Fig. 8.2). The X data can be viewed by selecting Real trace coordinates as in Fig. 8.3. The Y position

change data can be viewed by selecting Imaginary coordinates as in Fig. 8.4. With the order tracking measurement approach, you also have the advantage of getting up to four additional orders from the one pass through the data.

The computed order analysis software option can measure the shaft center line data by tracking order zero. However, the change in center line position from the shaft's at-rest position is the desired result. Again, waveform math is used to extract and format the change in shaft center line position versus RPM or time. The waveform math subtracts the shaft's at-rest center line position from each RPM value. These X and Y "static" gap change values are combined into one data record of orthogonal data pairs as was done in the slow roll removal example.

In this shaft centerline example a single waveform math function below does the calculation:

$$F5 = ((Track51/K2) - K1) +$$
$$K4*((Track52/K2) - K3)$$

Track 51 and track 52 are the mean (order 0) X and Y gap in mils Pk versus RPM (Fig. 8.1 A and B). Order track register 5 is assigned to tracking order 0 for channels 1 and 2. The track 0 data in the DSA are two times their true value, and thus divided by K2 (K2 = 2), which scales the track 0 values back to their true values in mils. The at-rest X gap value in mils Pk is entered into constant K1 and the Y at-rest value in mils is entered into K3. The subtraction of the at-rest X-Y values from the remaining

Fig. 8.1
The traces A and B are the Bodé plots of order zero for the X and Y proximity probes, which include the at-rest offsets.
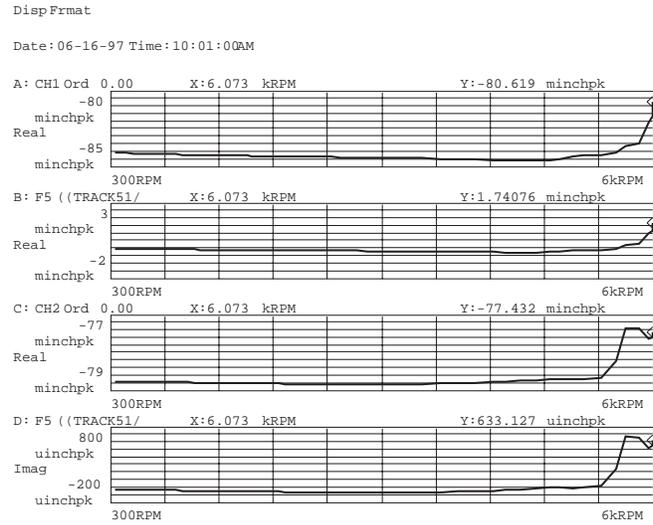
Fig. 8.2
By subtracting out the at-rest values from the order zero data and combining the results in a Nyquist Diagram of X versus Y, an axial view of the shaft position change versus RPM is produced.
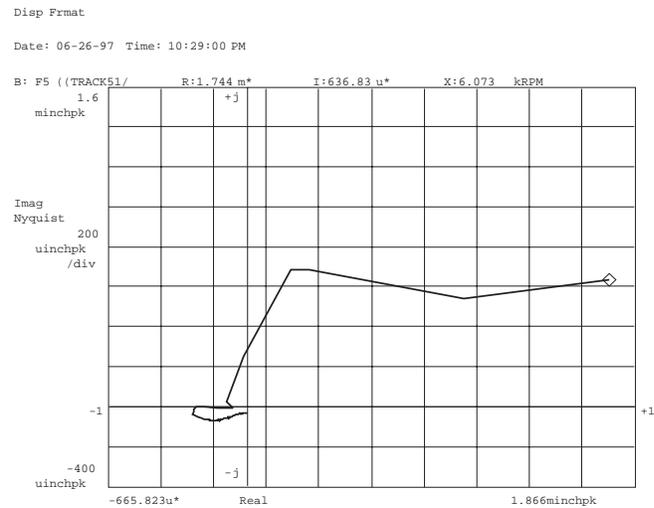
values isolates the change in gap versus RPM. The Y gap change is multiplied by K4 (K4 = 0 + j1). The Y axis data is thus converted to imaginary data (+90° rotation) and the addition combines Y gap data with X gap data into one data record.

The measurement setup also tracks orders 1, 2, 3, and 4 for two inputs, measured with a 50 RPM increment arming from 600 to 6000 RPM as in Fig. 8.1 A and B. The step-by-step procedure at the end of this section takes you through the process.

Some Cautions:

When working with "real" machine data, it is highly recommended that you audit the data by making some independent measurements, in addition to the at-rest measurements, using an integrating digital voltmeter. The independent measurements of the gap voltages and manually scaling the values to mils will provide a means to cross-check your results against those measured by the DSA. The results should be reasonably close. If the two results are not within ±0.5%, recheck both the hand-calculated and the DSA results to understand the disagreement. One thing to watch out for is the DSA's default data scaling applied to the math results. Be sure that all Y-axis scales are in REAL and Pk mils for order zero data. The first time calculated data is displayed on a DSA, it will be displayed in its default Y-axis scale of dB and rms units. Even if the units on a trace are set to REAL Pk, they may be reset to RMS scaling if measured trace data are changed.

Fig. 8.3
The X position change is viewed by selecting trace coordinate Real Part for the math function F5.
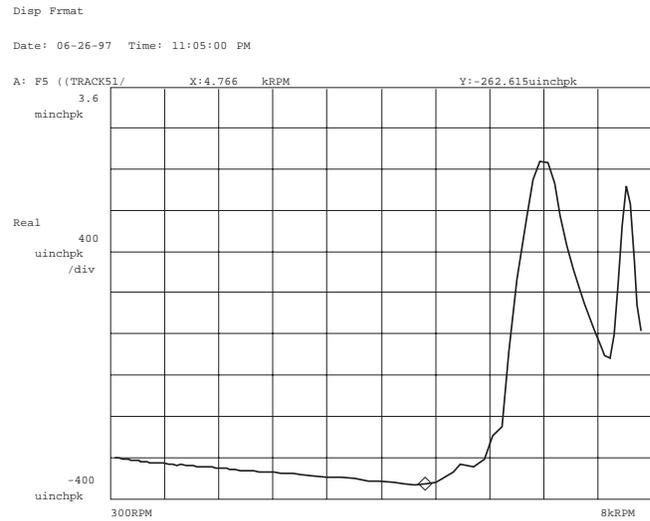
Fig. 8.4
The Y position change is viewed by selecting trace coordinate Imaginary Part for the math function F5.
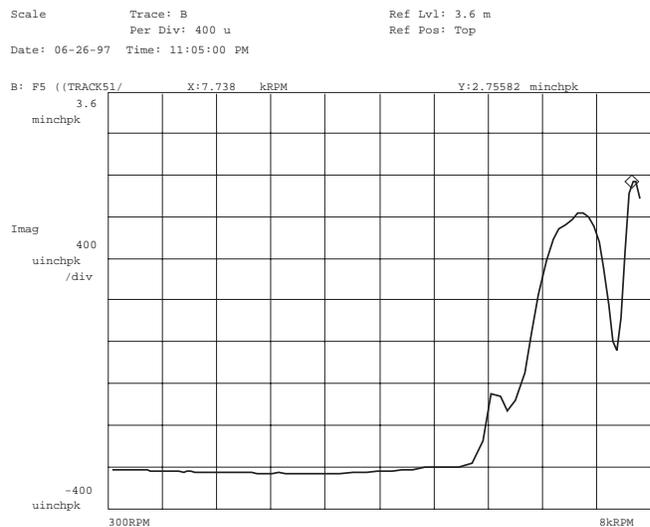
Example of Shaft Center Line versus Speed or Time Measurement

Shaft center line position change versus RPM measurements on fast startup transients were very difficult to make. The diagnostic measurements of center line shifts for startup transients were usually done with fast-sampling integrating digital voltmeters/data acquisition instruments or one settled for measurements sampled on hourly intervals as in heat soaks.

The example will illustrate how easy these measurements are to make using an Agilent DSA. Again, waveform math is used to extract and format the data to display the change in center line position versus speed. In this example, the data came from a rotor kit fitted with X and Y proximitors with 200 volts per inch (200 mv/mil) sensitivity. A two-channel 25 second, time capture of a rotor runup transient from 300 to 8000 rpm provides the X, Y probe data for tracking order 0. The DSA's analog inputs were DC coupled and grounded for this data capture. The 35670A's 16-bit analog-to-digital converter provides more than enough dynamic range to measure the DC gap voltage (-4V to -18V) and the dynamic order related vibration signals.

The order 0 Y axis coordinate is set to REAL and the Y units are set to Pk (peak). Trigger arming is set to RPM increment, with an RPM step size of 50 RPM. The order track register 5 is set up to track order 0 for channels 1 and 2. The scaled at-rest X probe

voltage was -8.41V. The at-rest position would be -8.41V/200 mv/mil = -42.05 mils. This value is entered into constant K1. The scaled at-rest Y probe gap is -7.87V/200 mv/mil = -39.35 mils. This is entered into constant K3. The math function subtracts the at-rest position in mils from measured and scaled values in mils. The at-rest value in mils is not an absolute value in that zero volts does not equal zero gap.

Recalling the Example Measurement State

Recalling the example measurement state will set up the measurement parameters outlined above and configure the display traces. After the order track measurement is started, the order track 5 register results (order 0) are extracted from the time capture buffer and displayed in the A and C traces. The at-rest X-Y gap values were entered into K1 and K3 constants for math function F5. The at-rest values are subtracted from the zero order data for display in the B and D traces.

Insert the disk "Agilent 35670A Rotor Dynamics Measurements Techniques" into the analyzer.
Press:

> **Save / Recall** → CATALOG ON / OFF → ON

Rotate the marker knob to highlight the file name "RNUPDC.TIM".
Press:

> RECALL DATA → RECALL CAPTURE

Verify that the prompt at the top of the analyzer screen shows "RECALL CAPTURE = RNUPDC.TIM".
Press:

> ENTER

Recalling the time capture file will require about one minute.

Rotate the marker knob to highlight the file "CNTRLN.STA".
Press:

> **Rtn**
> RECALL STATE

Verify that the prompt at the top of the analyzer screen shows "RECALL STATE = CNTRLN.STA".
Press:

> ENTER

Rotate the marker knob to highlight the file "CNTRLN.MTH" and then press:

> **Rtn**
> RECALL MORE
> RECALL MATH

Verify that the prompt at the top of the analyzer screen shows "RECALL MATH = CNTRLN.MTH".
Press:

> ENTER

To view the math, press:

> **Analys** → DEFINE FUNCTION

and verify the math and constants are the same as the following:
F5 = ((TRACK51/K2) - K1) + K4*((TRACK52/K2) - K3)
K1 = -4.20500e-2 +j 0.00,
K2 = 2.00 + j 0.00,
K3 = -3.93500e-2 + j 0.00
Press:

> **Disp Format**
> **Start**

to bring up a data display and to start the measurement.

The X probe 0 order data are tracked in track 51 and the Y probe data in track 52; unscaled results will build in traces A and C. The result of the math function that divides track 0

by 2 and subtracts the at-rest shaft position values will build in display traces B and D. Marker track is on so the markers will track the latest data points and display their numerical values in all four traces. The measurement will produce results as shown in Fig. 8.1. When the measurement is complete, rotate the marker knob to set the marker at the start of the track 0 data (approximately 300 RPM). Note the values in mils Pk in the A and C traces are very close to two times the at-rest values in mils.

The X versus Y position data are combined as Real and Imaginary values to provide an axial view of the shaft center line position change. The results are viewed by making the B trace active, setting up a single trace and selecting the Nyquist Diagram as the trace coordinates.
Press:

> **Active Trace** → B
> **Disp Format** → SINGLE
> **Trace Coord** → MORE CHOICES → NYQUIST DIAGRAM
> **Scale** → TOP REFERENCE →**1.5** → BOTTOM → **-0.5** → milli EXP-3

From the measurement result, the shaft is seen to be pulled down and wallows around at low RPM. At about 5400 RPM, the shaft climbs up the oil film (Fig. 8.2).

From the measurement, it appears that an RPM increment of 50 is a little too coarse as the speed ramps between 5400 RPM and 6000 RPM. Use the marker knob to evaluate the X-Y position change versus RPM.

Save the data in data register D1 to compare with next result. Press:

> **Save Recall** → SAVE DATA → SAVE TRACE → INTO D1

The RPM increment will be decreased in an attempt to improve the resolution and the speed range will be extended from 6000 RPM to 8000 RPM. Press:

> **Freq** → MAX RPM → **8** → KRPM

The RPM increment is reduced to 25 RPM as follows:
Press:

> **Trigger** → ARM SETUP → RPM STEP SIZE → **25** → RPM
> **Start**

When the measurement is complete press:

> **Active Trace** → A
> **Meas Data** → MORE CHOICES → DATA REGISTER → D1
> **Active Trace** → A B
> **Scale** → TOP REFERENCE → **3** → BOTTOM → **-0.5** → MILLI EXP-3
> **Active** → B
> **Disp Format** → SINGLE FRONT/BACK
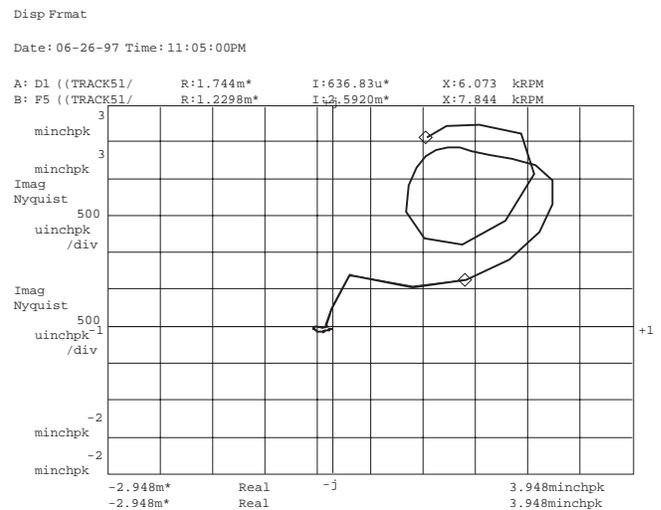> **Marker** → COUPLED ON OFF → ON

Rotate the marker knob slowly to observe the data point values. The shaft position changes above 6000 RPM get rather interesting.

The result of overlaying Fig. 8.2 with the new measurement shows that there was a very small improvement in the measurement point spacing (Fig. 8.5). The lack of additional measurement points indicates that the speed ramp rate was too fast above 5400 RPM to provide enough samples to produce additional measurement at the 25 RPM spacing. The shaft center line position change above 6000 RPM is very interesting and this behavior has repeated over several runups.

Manual Setup

The manual measurement state setup procedure for Section 8 is found in Appendix B.

Fig. 8.5
The overlay of the 6000 RPM and the 8000 RPM Nyquist Diagrams of position change show very little improvement in RPM resolution above 5400 RPM due to too fast of a speed ramping.

Disp Frmat

Date:06-26-97 Time:11:05:00PM

A: D1 ((TRACK51/   R:1.744m*   I:636.83u*   X:6.073 kRPM
B: F5 ((TRACK51/   R:1.2298m*   I:2.5920m*   X:7.844 kRPM

Order Magnitude-Phase-RPM Numerical Display

One of the well-liked features of the Digital Vector Filter Analyzer was its large numerical display of magnitude, phase, and RPM. The numerical display of data is often preferred over spectra during heat soaks and long-term monitoring of machines. The DVF's large numerical display of a selected order could be viewed from some distance away.

A very flexible numerical table of order magnitude, phase, and RPM is available in the 35670A. The 35670A data table can be set up for display of Pk-Pk order magnitude, phase and RPM for 10 or more orders from two inputs or for three or more orders on up to four inputs. The data table shows selected values from any measured data and trace coordinates in the analyzer. The desired display is provided by the Data Table function in the Analysis menu. A large multi-sync display terminal can be attached to the 35670A video output to increase the display size for remote viewing. The example that follows provides the step-by-step procedures for data table setup in the 35670A.

Example: Numerical Display of Order Magnitude, Phase, and RPM Setup

With waveform math, live magnitude, phase, and RPM are available from the Computed Order Analysis instrument mode. The order data records are Fourier transformed and displayed. The polar coordinate display is selected to provide both the magnitude and phase in one trace. The data table is set up with the required orders to be displayed as in

Fig. 9.1. The numerical display table overlays the spectrum in the background. The displayed values are specified orders, frequencies, or times from the background trace.

In this example, the runup time capture data, state, and math files are recalled to quickly display the data tables and how they function. The next part of the example is a step-by-step walk through of the key sequences to set up the data tables.

Fig. 9.1
The data table on the Agilent 35670A provides a live numerical display of the data from the background trace it overlays.
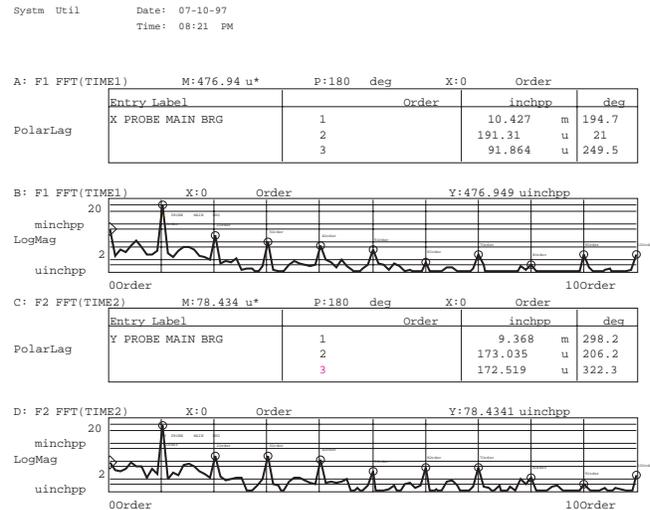
Recalling the Files

Insert the disk "Agilent 35670A Rotor Dynamics Measurements Techniques" into the analyzer.
Press:

> **Save / Recall** → CATALOG ON / OFF → ON

Rotate the marker knob to highlight the file name "RNUPAC.TIM".
Press:

> RECALL DATA → RECALL CAPTURE.

Verify that the prompt at the top of the analyzer screen shows "RECALL CAPTURE = RNUPAC.TIM".
Press:

> ENTER

Recalling the time capture file will require about one minute.

Rotate the marker knob to highlight the file "DSPNUM.MTH" and then press:

> **Rtn**
> RECALL MORE
> RECALL MATH

Verify that the prompt at the top of the analyzer screen shows "RECALL MATH = DSPNUM.MTH".
Press:

> ENTER

Rotate the marker knob to highlight the file "DSPNUM.STA".
Press:

> **Rtn**
> RECALL STATE

Verify that the prompt at the top of the analyzer screen shows "RECALL STATE = DSPNUM.STA".
Press:

> ENTER
> **Disp Format**
> **Start**

The numerical values will begin to update in the table as the data in the spectra are updated every 60 RPM.
Press:

> **Disp Format** → UPPER LOWER
> **Start**
> **Active Trace** → CD

Measurement State Setup

The manual key strokes that were used to set up the measurement state on the disk are:

> **Preset** → DO PRESET
> **Inst Mode** → ORDER ANALYSIS →
> TIME CAPTURE →
> MEASURE FROM INPUT BUFR → BUFR
> **Input** → ALL CHANNELS →
> XDCR UNIT CH* SETUP →
> XDCR UNITS ON OFF → ON →
> XDCR SENSITIVITY → **200** →
> V/EU → XDCR UNITS LABEL →
> MORE CHOICES → INCH
> **Freq** → MIN RPM → **300** → RPM →
> MAX RPM → **8** → KRPM
> **Trigger** → EXTERNAL TRIGGER →
> ARM SETUP → RPM STEP ARM →
> RPM STEP SIZE → **60** → RPM

Waveform Math

The waveform math functions F1 and F2 calculate the linear spectra for use in the data table.

The waveform math equations for linear spectra are:

$$F1 = FFT \text{ (Time 1)}$$
$$F2 = FFT \text{ (Time 2)}.$$

If your 35670A has 4 inputs you can also define:

$$F3 = FFT \text{ (Time 3)}$$
$$F4 = FFT \text{ (Time 4)}$$

The key sequence is as follows:

> **Analysis** → MATH FUNCTION →
> DEFINE FUNCTION → DEFINE F1 →
> OPERATION → FFT(→ MEASURED DATA →
> CHANNEL 1234 → **1** → TIME1 →) →
> ENTER
> DEFINE F2 → OPERATION → FFT (→
> MEASURED DATA → CHANNEL 1234 → **2** →
> TIME2 →) → ENTER

Display Setup

To display magnitude and phase of channel 1, make trace A active. Press:

> **Active Trace** → AB
> **Disp Format** → QUAD → MORE → PHASE LAG ON OFF → ON
> **Meas Data** → MORE CHOICES → MATH FUNCTION → F1
> **Active Trace** → CD → F2
> **Active Trace** → ABCD →
> **Trace Coord** → LOG MAGNITUDE → Y UNITS → AMPLITUDE PP PK RMS → PP
> **Scale** → AUTOSCALE ON OFF → ON
> **Active Trace** → A
> **Trace Coord** → MORE CHOICES → POLAR DIAGRAM
> **Analys**→ DATA TABLE → TABLE ON OFF → ON
> **Active Trace** → C
> **Trace Coord** → MORE CHOICES → POLAR DIAGRAM
> **Analys** → DATA TABLE → TABLE ON OFF → ON
> **Active Trace** → B
> **Marker** → MARKER ON OFF → ON → COUPLING ON OFF → ON → MARKER TO PEAK

The marker will be set to the peak value in the B trace, which will be order 1. The magnitude and phase of the first order can be read at the top of the A and C traces and in the data tables (Fig. 9.1).

Any order can be selected for the table by moving the marker to the ORDER and pressing:

> **Analys** → DATA TABLE → SELECT X ENTRY → **11** → INSERT X VALUE → **Marker Value**

Note: The **Marker Value** button is in the numerical key block.

The 11 is the table line number. The order is selectable over the measurement range with a resolution set by the delta order value in the 35670A. Press:

> **Start**

As soon as data appear in the trace, press the

> **Pause Cont**

button. This will pause the measurement. The next few steps will set up the data tables for all traces. First, all four traces will be overlaid by data tables.
Press:

> **Active** → ABCD
> **Analys** → DATA TABLE ON OFF → ON → OFF → ON

Next, the data tables will be cleared and then be set up to monitor the first 10 orders. With all traces active, press:

> CLEAR TABLE → CONFIRM CLEAR → SELECT X ENTRY

Fig. 9.2
The data tables are overlaying the background traces and reflect the specified data available in that trace.

```
Disp Frmat


A: F1 FFT(TIME1)        M:12.013 u*        P:336.22 deg       X:600     mOrder
          Entry Label                        Order       inchpp        deg
                                               1          1.366    m  145.2
PolarLag                                       2          51.391   u   32
                                               3          92       u  335


B: F1 FFT(TIME1)        X:600     mOrder                   Y:12.0132 uinchpp
          Entry Label                        Order              inchpp
                                               1              1.366        m
LogMag                                         2              51.391       u
                                               3              92           u


C: F2 FFT(TIME2)        M:8.6013 u*        P:22.546 deg       X:600     mOrder
          Entry Label                        Order       inchpp        deg
                                               1         833.466   u  239.2
PolarLag                                       2         236.355   u  225.6
                                               3          69.764   u  314.8


D: F2 FFT(TIME2)        X:600     mOrder                   Y:8.60132 uinchpp
          Entry Label                        Order              inchpp
                                               1            833.466        u
LogMag                                         2            236.355        u
                                               3             69.764        u
```

The analyzer will echo:

"SELECT X ENTRY = 1" →
ENTER → INSERT X VALUE

which will echo "INSERT X VALUE = 0". At this point press:

1 → ORDERS

This will enter order #1 as the data in table position one. The X entry will automatically index to 2.
Press:

INSERT X VALUE → **2** → ORDERS → **3** →
ORDERS → **4** → ORDERS → **5** →
ORDERS → **6** → ORDERS → **7** →
ORDERS → **8** → ORDERS → **9** →
ORDERS → **10** → ORDERS

The automatic indexing will have filled the first 10 table positions with your selected data.
Press:

MARKER ON OFF → ON →
SELECT X ENTRY → **1**

Rotate the knob to scroll through the tables and return so that entry 1 is at the top of the data table. Note how the data table has automatically picked the x and y coordinate values from the background traces associated with the orders specified (Fig. 9.2).

We will now deactivate the data table for Traces B and D.

Active Trace → B → TABLE ON OFF →
OFF → **Active Trace** → D
TABLE ON OFF → OFF

The data tables overlay the traces in the background and can reflect all or part of the data in the trace. The A and C traces are polar diagrams, which are three-dimensional plots with magnitude and phase in the plane view and the order axis coming out of the DSA screen. The data table reflects the magnitude and phase for the selected orders in the trace. The

data table for B and D traces with a magnitude spectra can display magnitude only. (Fig 9.1)

In the data table menu press:

MARKER ON OFF → OFF → ON

and observe the effects on the active trace D. Press:

Start

Note that the orders listed in tables and traces are updated automatically every 60 RPM as the analyzer reduces the data in the capture file. The final result at 8000 RPM will be very close to the results in Fig. 9.3.

Labeling Table Entries

Table entries are easily labeled using the alpha subscripts of the front panel buttons or by using an external PC keyboard.
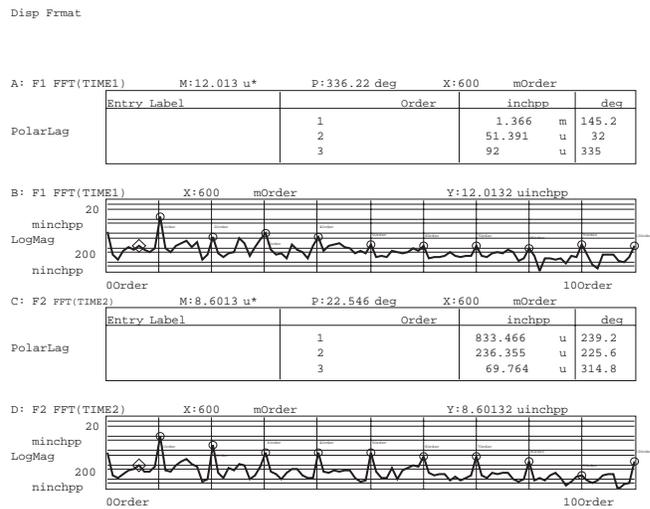Press:

Active Trace → ABCD
SELECT X ENTRY → **1** → ENTER →
ENTRY LABEL

The echoed message will be "ENTRY LABEL =   " and the DSA will be in the alpha mode ready for the alpha characters to be entered. Enter:

X → INSERT SPACE → **P R O B E** →
INSERT SPACE → **M A I N** →
INSERT SPACE → **B R G** → ENTER

Fig. 9.3
The data tables overlaying the polar plot in traces A and C display magnitude in PP mils and phase lag. When the data table marker is on as in the linear spectra of B and D traces, the table is shown.

The label has been entered in all the data tables for entry #1. Next, the label for the C and D traces are modified. Press:

Active Trace → CD → ENTRY LABEL

The prompt line "ENTRY LABEL = X PROBE MAIN BRG" will appear. Turn the marker knob to highlight the "X "and Type the letter "Y" and press:

DELETE CHARACTER

to delete the "X". Press:

ENTER

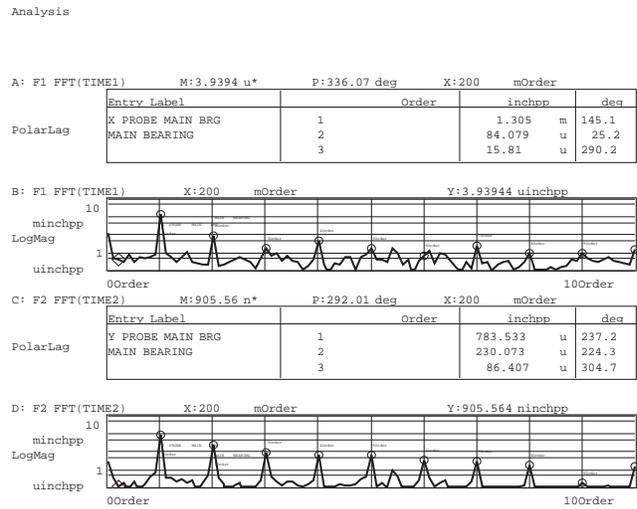and the label now reads "Y PROBE "MAIN BRG". The result will look like Fig. 9.4.
Press:

Active Trace → AB
Disp Format → UPPER LOWER
Start

The Data Table Marker function also prints the last table entry values on the associated spectral plots as shown in Fig. 9.5

The 35670A video out can be connected to a large screen multi-sync monitor, which makes the data tables much more visible. The monitor can be located some distance from the DSA. The data tables allow you to observe the stability of the order's magnitude and phase numbers during heat soaks without the need to be right in front of the analyzer. Multi-sync monitor technology and models are changing rapidly. It may be necessary to use a video amplifier or converter for this to work correctly.

Fig. 9.4
The data table entry lines can be labeled as required line by line.

Analysis

A: F1 FFT(TIME1)   M:3.9394 u*   P:336.07 deg   X:200   mOrder

Entry Label	Order	inchpp		deg
X PROBE MAIN BRG	1	1.305	m	145.1
MAIN BEARING	2	84.079	u	25.2
	3	15.81	u	290.2

PolarLag

B: F1 FFT(TIME1)   X:200   mOrder   Y:3.93944 uinchpp

C: F2 FFT(TIME2)   M:905.56 n*   P:292.01 deg   X:200   mOrder

Entry Label	Order	inchpp		deg
Y PROBE MAIN BRG	1	783.533	u	237.2
MAIN BEARING	2	230.073	u	224.3
	3	86.407	u	304.7

PolarLag

D: F2 FFT(TIME2)   X:200   mOrder   Y:905.564 ninchpp

Fig. 9.5
The label as well as the order, frequency, or time values from the data table are printed on the plots next to their associated marker as on the trace above.

Disp Frmat

B: F1 FFT(TIME1)   X:200   mOrder   Y:3.93944 uinchpp
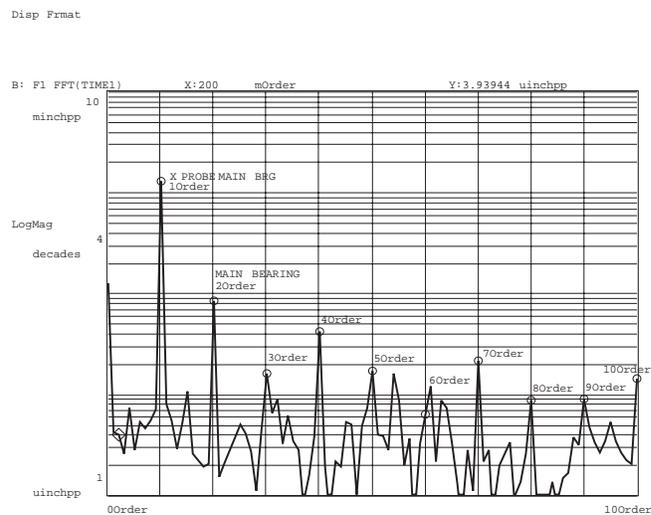
Fig. 9.6
**An external monitor allows the Agilent 35670A display to be enlarged and placed remote from the DSA.**
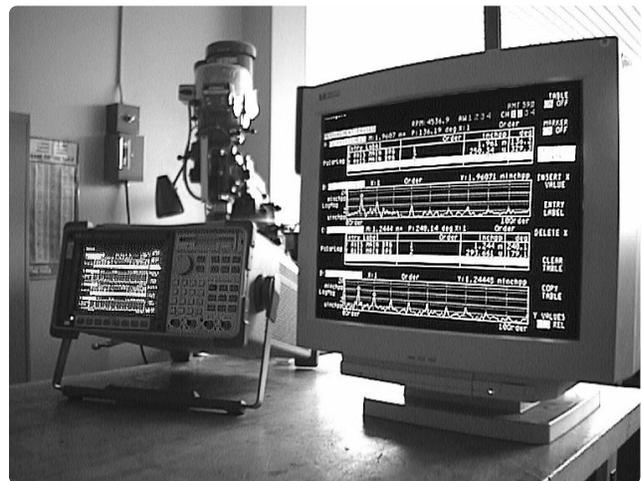
Section 10
# Proximity Probe Interfacing

Proximity probes are in a general class of non-contacting displacement transducers. Several position sensing techniques are used by non-contact displacement transducers, including capacitance, optical, laser, and inductive (eddy current) transducers. The most widely used non-contacting probes on rotating machinery are the eddy-current type, commonly known as proximity probes. Proximity probes are used because they are durable, and they can directly measure shaft to bearing clearance. (Fig. 10.1).

The eddy-current proximity probes consist of two parts, the probe and the oscillator/demodulator (Fig. 10.2). The high-frequency oscillator is used to induce an eddy current on the shaft's surface without actually touching it. The eddy-current probes can sense the gap between the probe tip and the conductive surface of the rotating shaft. As the shaft moves relative to the sensor, more or less energy goes into the eddy current. These eddy-current energy changes modulate the amplitude of the oscillator voltage. This signal is demodulated, providing an output voltage proportional to the change in gap. In a typical proximity probe the voltage output is a modulated signal with a large negative DC voltage bias, or "set" point.

**Fig. 10.1
A typical proximity probes configuration in fluid film bearing.**

Y Proximity Probe

X Proximity Probe

View from drive end of the shaft
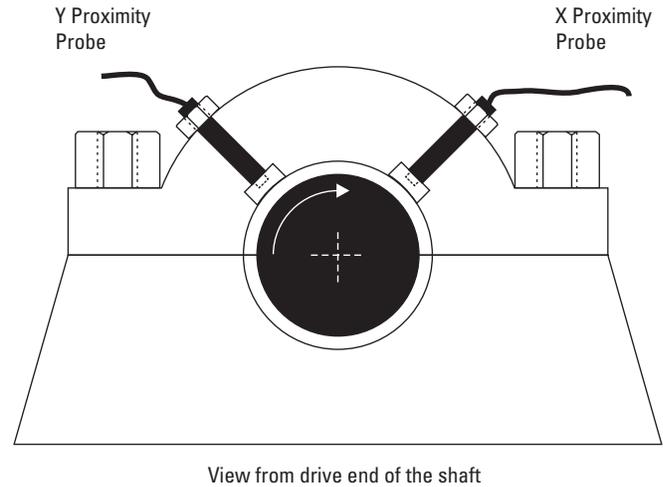
**Fig. 10.2
An eddy current proximity probe consists of two parts, the probe and the oscillator/demodulator.**

Eddy Current Probe

Oscillator/ Demodulator
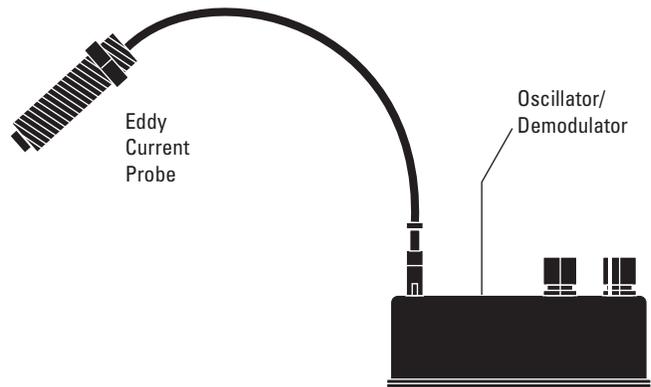
As the rotating surface moves away from the probe tip, less eddy current energy is lost and the voltage output of the demodulator becomes more negative. As the gap gets smaller, more eddy current is lost in the shaft surface and the output becomes less negative. The indicated gap change causes the voltage to change about the probe's set point.

For example, a proximity probe with a 200 millivolt/mil sensitivity will show a periodic one volt peak-to-peak signal when measuring a 5 mil peak-to-peak displacement. (Fig 10.3) The signal period will match the displacement. So, if the 5 mils peak-to-peak occurs once per revolution, the signal period will match this speed. Proximity probes are ideally adjusted for an operating set point in the middle of the probe's linear operating range. Typically, a -24V unit will have a linear operating range from -2V to -22V with a recommended set value of -12V. Similarly a -18V unit operates linearly from -2V to -16V with a recommended set value of -7V.

Proximity Probe Interfacing

The interfacing of proximity probe outputs to the 35670A is a direct connection. The 35670A provides a maximum input range of up to ±31V peak. The DC operating point of the proximity probe output is well within this range. The 35670A has more than enough dynamic range to measure a small dynamic signal (<10 mv) plus the probes negative DC operating point offsets.

Set the input coupling to be DC by pressing:

> **Input** → FRONT END CH* SETUP → INPUT LOW FLOAT GND → GND → COUPLING AC DC → DC

If greater signal dynamic range is required, the AC coupling should be selected. Measurements below 180 RPM will have slightly degraded channel-to-channel phase match and amplitude attenuation when AC coupling is used. For a proximity probe with a sensitivity of 200 millivolts/mil, enter 200 volts/inch for EU (Engineering Units). The engineering units of 200 millivolt/mil of a proximity probes is equal to 200 volts per inch.

By using the fundamental units of inches, you avoid the problem of strange units such as milli mils instead of µ inches appearing on your plots. Set up Engineering Units (EU) by pressing:

> **Input** → TRANSDUCER SETUP → EU ON OFF → ON → TRANSDUCER SENSITIVITY → **200** → VOLTS PER EU → EU LABEL → MORE CHOICES → INCH

The DSA's signal return (low) is connected to the common on the oscillator/demodulator. The oscillator/demodulator output is connected to the signal input (high).

Fig. 10.3 Calibration curve of an ideal, linear, proximity probe.

Proximitor static output gap voltage (negative volts DC) vs. Distance between probe tip and target (mils)
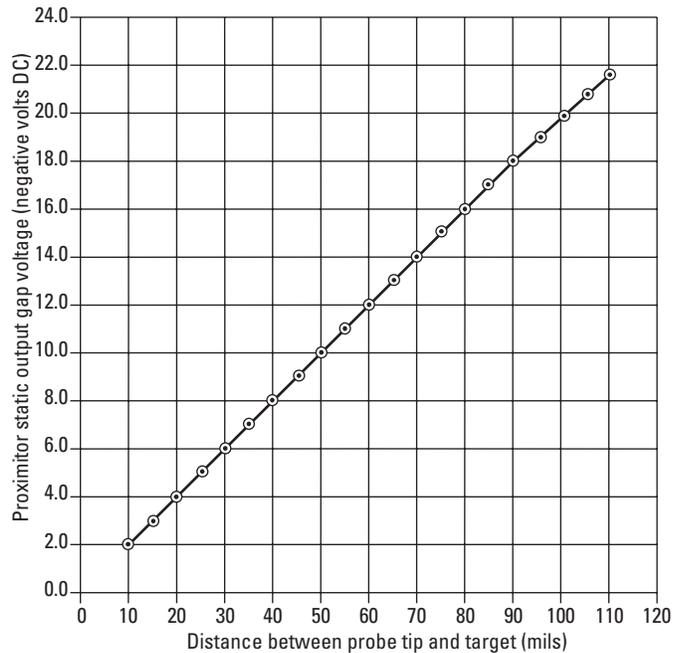
Section 11
Keyphasor Interfacing

Keyphasors are often found on critical machine assets along with proximity probes. The keyphasor provides a once-per-revolution φ reference signal for angular measurements on a rotating shaft. If you have access to this signal, it will save you the trouble of attaching a once-per-revolution phase reference to the shaft. The purpose of a keyphasor is to relate the rotating reference frame of the shaft to the stationary reference frame of the vibration or displacement sensors. A key-phasor sensor has similar output voltage characteristics as a proximity probe shown in Fig. 11.1.

The ideal keyphasor signal would have a very fast and large change in voltage as a high or low spot edge passes under the probe. The optimum setup for an eddy current phase sensor is to adjust it for a maximum voltage swing. In the case where a slot (keyway) is the reference transition, the probe "sees" a small gap for almost the complete revolution. The keyphaser output will ideally be in the -2 to -5 volt range for this small gap portion of the revolution of the shaft. When the key slot passes under the keyphaser probe, the output will peak to the -16 to -22 volt range (Fig. 11.2).

In the case where the key is the high spot the probe "sees" a large gap for almost the complete revolution. As a result the output voltage will be in the -16 to -22 volt range for most of the shaft's rotation. As the key (high spot) passes under the probe, the keyphasor output will swing to the -5 to -2 volt range (Fig. 11.2).

Typically, the manufacturers recommend having a minimum of 60 mils between the high/low spot transition, which will produce a 12-volt swing. The key or slot should be at least two probe tip diameters in width. In the field, you are likely to encounter a very large variation from these ideal phasor voltage signals. In one case, a

Fig. 11.1
A typical keyphasor setup with a slot (key slot) passing under the probe. The voltage swing goes from the -2V to -5V range for almost the complete revolution to the -16V to -22V as the slot passes under the probe.
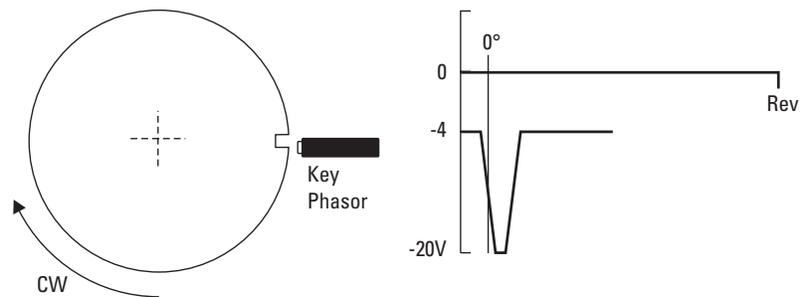
Fig. 11.2
A typical keyphasor setup with a key (high spot) passing under the probe. The voltage output is -16V to -22V range for almost the complete revolution, but goes to -2V to -5V range as the key passes under the probe.
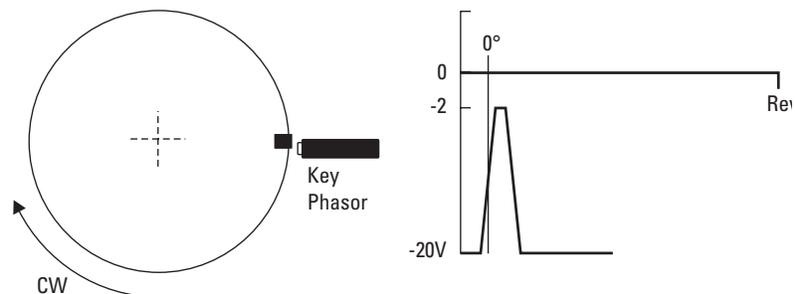
flat of only a few mils was ground on a shaft surface. The keyphasor signal was useless because the shaft dynamics produced a larger signal than the flat.

Two inputs on the DSA can interface to a once-per-revolution phase reference. They are the tach input and the external trigger input. The tach input can be set up to handle from 1 to 2,048 pulses per revolution. The external trigger input requires a once-per-revolution pulse to identify the shaft time 0 or angle 0 reference. The phase reference can be input to the external triggering input or to any one of the analog input channels. Even when the tach input is only one pulse per revolution, the once-per-revolution phasor signal needs to be connected to a trigger input if phase is to be extracted from the measured data. The separation of the tach and trigger inputs allows the DSA to take full advantage of the better angular accuracy available from a multiple-pulse-per-revolution tach.

The best practice is to first view the keyphaser signal and determine the optimum trigger level and slope to ensure a reliable firing on the leading edge of the once-per-revolution phase reference. The example describes the interfacing issues for the 35670A in more detail.

Keyphasor Tachometer Interfacing

First, view the phasor signal and determine the optimum trigger level and slope. This is to ensure a reliable trigger on the leading edge (left hand, first transition) of the once-per-revolution phase reference. The

keyphasor signal should be connected to the tach input, external trigger and to the channel 1 input. Using BNC tees will make this easier. The external trigger and tach input are on the rear panel of the 35670A. The keyphasor signal should be a once-per-revolution pulse train ranging from -2 to -22 volts. The phasor tach signal is most easily viewed using the FFT mode to make time domain measurements in the DSA. Press:

> **Preset** → DO PRESET

This sets the Measurement Mode to the FFT ANALYSIS mode.
Press:

> **Meas Data** → TIME CHANNEL 1
> **Start**

and adjust the measurement time to view 2 to 4 tach pulses in a time record. To adjust time press:

> **Freq** → RECORD LENGTH

and use ⇑ to increase the measurement time to display the 2 to 4 pulses. Next press:

> **Pause**

and use the marker to determine the voltage swing of the phasor signal, slope of the leading edge, and its midpoint.

The tach input has two input ranges, ±20 and ±4 volts. Select the range that is appropriate for the phasor voltage swing, i.e., a swing from -5V to -15V would indicate a -10V trigger level (Fig. 11.2). The output of optical tachs is typically 0 to +5V and the ±4V trigger range would be selected and a level of +2.5V would be set as the tach trigger level.

Press:

> **Trigger** → TACHOMETER setup →
> TRG RANGE +/− 20 4

is toggled to a voltage range appropriate for the voltage swing of the phasor signal. Next press:

> LEVEL

and enter a level that is at the midpoint of the voltage swing. Next press:

> SLOPE

to toggle to the slope of the leading edge of the phasor signal. Since the leading edge is heading downhill for the keyphasor in

Fig. 11.3
A typical optical tach provides a TTL output level (0 to 5V). The EXT TRIGGER level selected would be compatible with TTL.
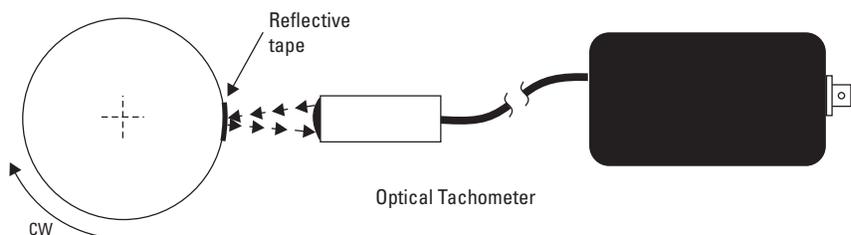

Reflective tape

Optical Tachometer

cw

Fig. 11.1, the slope NEG would be selected. The slope selection for the signal in Fig. 11.2 would be POS.

The trigger input on the 35670A provides both a ±10V and a ±2V trigger range. These can be used provided the phasor's output swings through -8V or -2V ranges. Moreover the phasor output must reach below a level of -10 V or triggering problems are likely due to shaft center line shifts with speed. The interfacing of a keyphasor signal outside the -8V range (-8V to -22V) can be handled by using a voltage attenuator. A 2 to 1 voltage divider can be easily set up by attaching a 40 kOhm 1/8 watt resistor to the keyphasor output terminal and connecting it to a BNC adapter. (As shown in Fig 11.4). This series resistor should be inserted in the demodulator output line. Using a BNC adapter with alligator clips makes this very easy. However great care should be used to avoid shorting out the demodulator. The use of insulating sleaving on the resistor lead is highly recommended. Typically the red lead in the adapter is the center, or signal line. Connect the signal line to the other end of the resistor. The attenuator will bring the -10V to -20 levels down to the -5V to -10 range, well within the ±10V trigger range.

Another approach to the keyphasor interfacing problem is to use a blocking capacitor (Fig. 11.5). A polarized capacitor of 20 to 50 µF with 50V or higher voltage rating will work well. The capacitor will block the DC portion of the signal and allow the dynamic part to pass through.

It is recommended that the attenuated or AC coupled keyphasor signal be measured and viewed. To view the signal, connect it to the TACH INPUT, TRIGGER INPUT, and to CHANNEL 1 input. As described previously, use the FFT mode to display the time domain tachometer signal. Change the Record Length using the frequency menu to view 2 or 3 tach pulses. With the marker you can easily determine the tachometer signal voltage swing and midpoint. You can then set the tachometer parameters correctly. Press:

> **Trigger** → TACHOMETER setup →
> EXT LEVEL USER TTL →
> USER TRG RANGE ±10 2 → **10**

Next press:

> LEVEL

and enter a level that is at the midpoint of the voltage swing if possible.

Next press:

> SLOPE NEG POS

to toggle to the slope of the leading edge of the phasor signal. Turn on the tachometer display and set the trigger levels.

> TACH DISP ON OFF → ON → **Rtn** →
> EXTERNAL TRIGGER → TRIGGER SETUP →
> EXT LEVEL USER TTL → USER →
> USER EXT LEVEL

is set to an appropriate level. Set:

> SLOPE POS NEG →

To an appropriate value.

The tach signal and the tach display should now appear stable. If the tach display and waveform are not stable or a "WAITING FOR TRIGGER" message appears, recheck the level and hookup. Refer back to the paragraph above on attenuating the phasor signal for the trigger input.

Fig. 11.4
A simple 2 to 1 attenuator can be made using a BNC to alligator clip adapter. The keyphasor output level will be brought down to within the ±10V range of the EXT TRIGGER INPUT of the Agilent 35670A.

Oscillator/Demodulator
-18V to -24V
COM
Output
40k Ohm
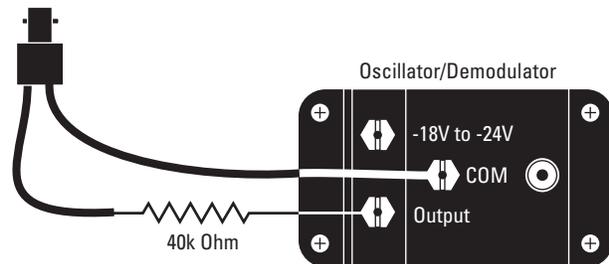
Fig. 11.5
Connecting a DC blocking capacitor to the keyphasor output terminal with a BNC to alligator clip adapter. The resulting keyphasor will be centered on VDC.
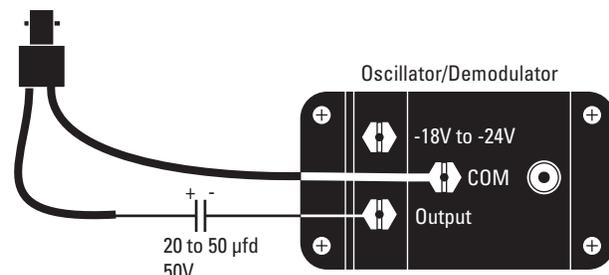
Oscillator/Demodulator
-18V to -24V
COM
Output
+ -
20 to 50 µfd
50V
Note correct capacitor polarity.

Slow Roll Removal

Manual Measurement State Setup

The following is the detailed step-by-step setup procedure for manually doing slow roll removal. This procedure is provided as a reference.

The **Inst Mode** is set to ORDER ANALYSIS. The order resolution is set to 1 order so 1 revolution per record is displayed (Fig. 4.3):

> **Freq** → DELTA ORDER → **1**

The proximity probes nominal engineering units values were entered by pressing:

> **Input** → ALL CHANNELS →
> XDCR UNIT CH* SETUP →
> XDCR SENSITIVITY 200 → V/EU →
> XDCR UNIT LABEL → MORE CHOICES →
> INCH → **Rtn** → **Rtn (pressed twice)**

Next press:

> XDCR UNIT ON OFF → ON

The 200 mv/mil calibration factor for the probe was entered as 200 V/inch. Using the basic units of inches instead of 200mv/mil will prevent strange units such as milli mils instead of μ inches from appearing on the X or Y axis.

Press:

> **Rtn**
> FRONT END SETUP → AC/DC → AC

AC coupling on the analog inputs was selected to block the -8V DC of the proximity probe that the dynamic gap signals ride on. An optical tachometer was used to produce the 0 to 5V once-per-revolution tach/trigger signal for the example data.

It is recommended that the tach signal be measured and viewed. The phasor signal can be connected to the tach and trigger inputs. The tach and trigger levels and the slopes should be set to fire in the middle of the leading edge of the tach signal. The tach level should be set so that no tach pulses are missed and there are no false triggers. The tach display is turned on and the stability of the RPM observed. Jumps in RPM are an indication of an inappropriate tach level. Magnetic tachs are especially prone to producing both unstable RPM displays and phase errors because their peak level, slope and wave shape are likely to change radically with RPM.

Setting up the analyzer for a 2 trace display for slow roll correction is done by pressing:

> **Freq** → MIN RPM → **300** → RPM
> **Trigger** → EXTERNAL TRIGGER →
> TRIGGER SETUP → EXT RANGE +/− 10 2 →
> ____ → USER EXT LEVEL → ?.? → V →
> SLOPE POS NEG → NEG →
> **Rtn** → ARM SETUP → AUTOMATIC ARM →
> RPM STEP SIZE → **40** → RPM
> **Avg** → AVERAGE ON OFF → ON →
> NUMBER AVERAGES → **1** → ENTER
> **Active Trace** → A
> **Meas Data** → CHAN 1 2 3 4 → **1** →
> TIME CHAN 1
> **Active Trace** → B → CHAN 1 2 3 4 → **2** →
> TIME CHAN 2

The math function is as follows:

$$F1 = (TIME1 - D1)$$
$$F2 = (TIME2 - D2)$$

The key path to enter the math is as follows:
Press:

> **Analysis** → DEFINE FUNCTION →
> DEFINE F1 → (→
> MEAS DATA CHANNEL 1 2 3 4 → **1** →
> TIME1 → − → Data reg →
> DATA REG D1 →) → ENTER.

Press:

> DEFINE F2 → (→ MEAS. DATA →
> CHANNEL 1 2 3 4 toggled to 2 and press
> TIME2 → − → DATA REG →
> DATA REG D2 →) → ENTER

The slow roll records of the X and Y proximity probes are saved in data registers D1 and D2. See the previous "Modifying the Measurement State" to continue the manual commands to complete the example.

Each new order record (TIME1 and TIME2) has the slow roll subtracted from it to provide a live display at two or more updates per second.

Appendix B
Shaft Center Line Position Change Versus Speed or Time

Manual Measurement State Setup

The manual measurement state setup procedure can proceed from two instrument starting points. The first is from the power up condition where the time capture, math, and state have all been reset to their defaults. The other start point is from the pre-set state. The preset state puts the DSA into the FFT ANALYSIS mode but retains the time capture, math, and the front end setup parameters. It is best to use the manual setup as a guide to learn how this measurement state is set up and to start from the preset point.

Starting from power up, load "CNTRLN.STATE" and "RNUPDC.TIM" records. Set up an Order Track Measurement by pressing:

> **Preset** → DO PRESET
> **Meas Mode** → ORDER ANALYS →
> TIME CAPTURE →
> MEAS FROM INP BUFR → BUFR

The track register 5 is set up to track order 0 for channels 1 and 2 by pressing:

> **Freq** → TRACK ON OFF → ON →
> TRACK SETUP → TRACK 5 ORDER → **0** →
> ORDERS → **Rtn** → MIN RPM → **300** →
> RPM
> **Active Trace** → ABCD
> MKR TRACK ON OFF → ON
> **Trigger** → EXTERNAL TRIGGER →
> ARM SETUP → RPM STEP ARM →
> RPM STEP SIZE → **50** → RPM

Press:

> **Analysis** → DEFINE CONSTANT →
> DEFINE K1

and enter the scaled at-rest X probe voltage (-8.41V/200 mv/mil = -42.05 EXP-3) and press ENTER. Verify the correct value is in K1. Press:

> DEFINE K3

and enter the scaled at-rest Y probe voltage (-7.87V / 200 mv/mil = -39.35 EXP-3) and press:

> ENTER

Entering the Math Function F5

The math function to scale and combine X and Y gap data is:

$$F5 = ((TRACK51/K2) - K1) + K4*((TRACK52/K2) - K3)$$

Track register 5 is set to track order 0 for channels 1 and 2. The results are in Measured Data TRACK 51 AND 52. The divide by K2 = 2 scales the order track 0 values to their correct values in mils.
Press:

> **Analysis** → DEFINE FUNCTION →
> DEFINE F5→ (→ (
> MEAS DATA → ORDER TRK CHAN 1 →
> TRACK5 → / → CONSTANT K1 - K5 →
> K2 →)
> – → CONSTANT K1 - K5 →
> CONSTANT K1→)
> + → CONSTANT K1 - K5 → K4 → * → (→ (
> MEAS DATA → CHANNEL 1 2 3 4 → **2** →
> ORDER TRK CHAN 2 → TRACK5 → / →
> CONSTANT K2 →) → – → CONSTANT K3
> →) →) → ENTER

The waveform math extracts the shaft center line X and Y position, order 0, and scales them. The at-rest values are subtracted to compute the change in position and combines the X-Y gap change data into a single record.

The Display Setup

The unscaled shaft center line position versus RPM is displayed by pressing:

> **Disp Format** → QUAD
> **Active Trace** → A
> **Meas Data** → MORE CHOICES →
> ORDER TRACK CHANNEL 1 →
> TRACK 5 ORDER 0.00
> **Active Trace** → C
> **Meas Data** → MORE CHOICES →
> CHANNEL 1 2 3 4 → **2** →
> ORDER TRACK CHANNEL 2 →
> TRACK 5 ORDER 0.00

The B and D traces are set to display the change in X and Y position extracted with math function F5.

> **Active Trace** → B
> **Meas Data** → MORE CHOICES →
> MATH FUNCTION → F5
> **Active Trace** → D → F5

The trace coordinates for the four traces are set up by pressing:

> **Active Trace** → A B C D
> **Trace Coord** → Y UNITS →
> AMPLITUDE PK PP RMS → PK
> **Rtn** → MORE CHOICES → REAL PART →
> **Active Trace** → D → IMAGINARY PART

Assuming you have correctly recalled the file RNUPDC.Tim, Press:

> **Start**

Scaling the traces is done by pressing:

> **Scale** → AUTOSCALE ON OFF → ON

and at the completion of the measurement press:

> AUTOSCALE ON OFF → OFF

The result should look much like Fig. 8.1.

To view the X versus Y shaft center line position change versus RPM, change the trace coordinates to NYQUIST DIAGRAM.
Press:

> **Disp Format** → SINGLE
> **Active Trace** → B
> **Trace Coord** → MORE CHOICES →
> NYQUIST DIAGRAM
> **Scale** → TOP REFERENCE → **1.6** →
> BOTTOM → **-0.4** → MILLI EXP-3

The Nyquist Diagram provides an end view of the shaft position change versus RPM in the sleeve bearing of the rotor kit (Fig. 8.2).

To display the X transducer position change, press:

> **Trace Coord** → MORE CHOICES → REAL
> **Scale** → TOP REFERENCE → **1.6** →
> BOTTOM → **-0.4** → MILLI EXP-3

The display on the 35670A will look like Fig. 8.3. The shaft is pulled to the left about 0.25 mils at low RPM and then moves to the right about 3 mils at 6400 RPM viewed from the motor end. The motor was turning counterclockwise.

To view the Y gap change versus RPM, press:

> **Trace Coord** → MORE CHOICES →
> IMAGINARY

The shaft stays at the at-rest position at low RPM and then rises up on the oil film as RPM increases (Fig. 8.4).

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