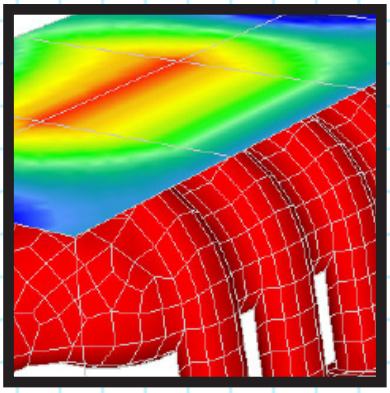
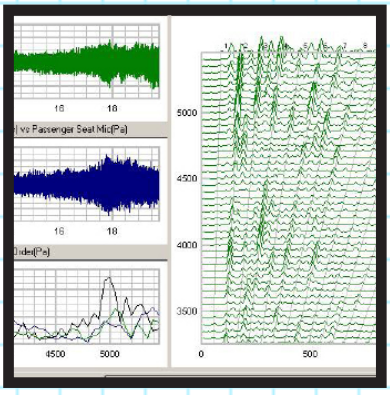
NOISE & VIBRATION MEASUREMENT HANDBOOK





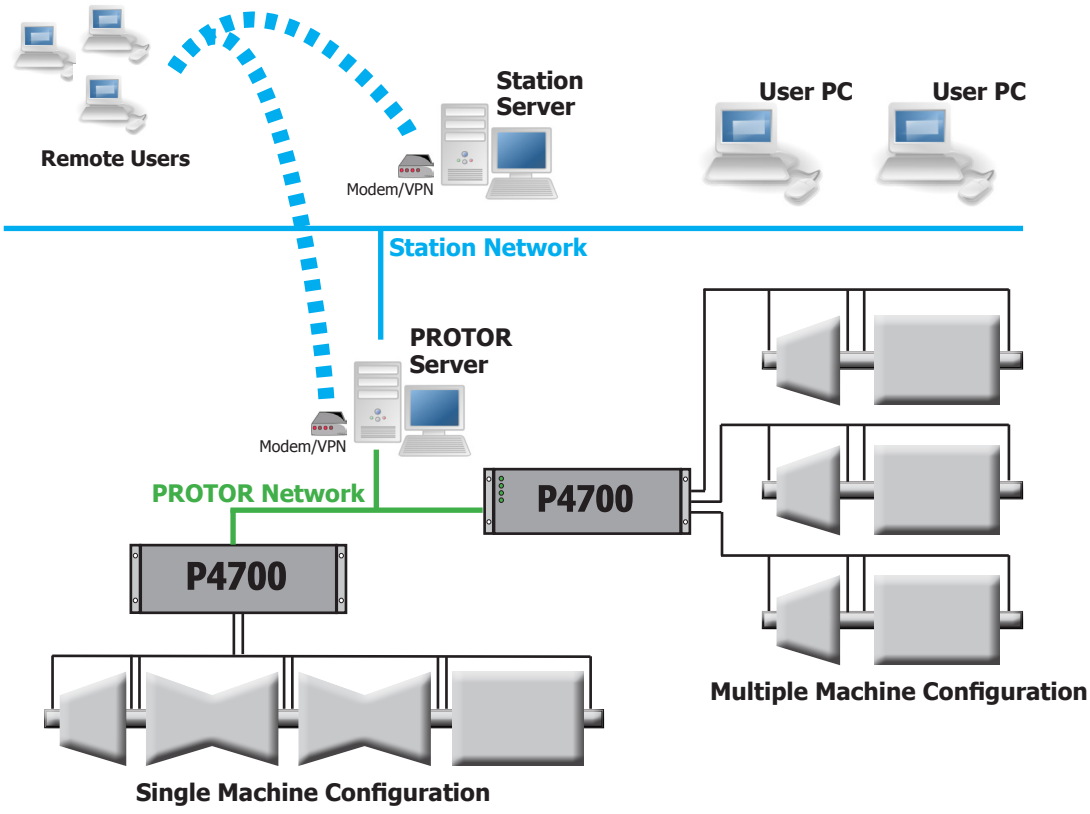
PROSIG Data Acquisition & Analysis Tools

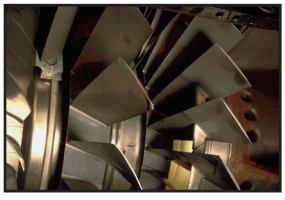
Third Edition

CONDITION MONITORING

PROTOR Condition Monitoring System

- Improve efficiency
- Reduce capital & running costs
- Improve safety
- Local & remote data access
- Turbine & auxiliary monitoring
- Wide range of fault detection
- Realtime & historic data
- Choice of data visualizations





PROTOR provides a complete hardware and software solution for vibration monitoring of rotating machines. Individual, multi-channel, distributed acquisition and processing subsystems are connected using standard networks to one or more database servers providing access to both realtime and historic data. Data is available locally and remotely on LANs, WANs and VPN/modems for display in a variety of graphical and numerical forms.

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local representative

PROTOR Benefits

- **Improved overall efficiency** by increasing machine uptime.
- **Improved safety** by decreasing the risk of machine failure.
- Continuous machine health information allows predictive maintenance, **avoiding and limiting machine damage**.
- **Reduced capital costs** by extending machine service life.
- **Decreased machine servicing costs** by only repairing or replacing those parts that are damaged or worn out.
- **Decreased machine repair costs** by recognizing problems before they cause serious damage.
- **Reduced machine downtime** by allowing machines to be maintained while in service.
- **Reduced risk of unplanned shutdowns** by allowing scheduled maintenance to coincide with production requirements.
- **Excellent data accessibility** bringing data to your desktop either locally or remotely.

PROTOR supports

- Bearing performance analysis
- Examination of critical runup / rundown modes
- Data comparison at known speeds
- Accurate and reliable trends
- Ability to set up accurate limits
- Examination of blade frequencies
- Full FFT processing of runup / rundown data
- Historical data storage
- Better control of machine rotor startup
- Remote access via modem, VPN or WAN

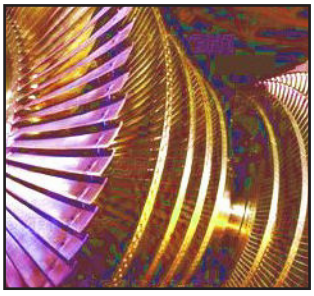
PROTOR can help detect

- Shaft unbalance
- Shaft bowing
- Shaft rubs
- Bearing faults
- Misalignment
- Looseness of rotating elements
- Balance piston rubs
- Generator shorts
- Blade response
- Shaft cracking
- Whirl problems
- Damaged sealing strips
- End winding vibrations
- Hub cracking

PROTOR provides comprehensive alarm checking, mimics, trends, vector plots, orbits, FFTs, waterfalls and so on, for real time and historic data.

Realtime & Historic Graphics include

- Runups
- Rundowns
- Mimic diagrams
- Orbits
- Vector plots
- FFTs
- Numerical displays
- Trend plots
- Order plots
- Waterfalls
- Demand time and spectra
- Reference overlays during runup and rundown
- Combined vibration and plant process parameter plots
- Cascade and overlay X-Y plots



Other Features

Extensive programmable signal conditioning facilities for

- shaft displacement / Eddy current probes
- IEPE devices
- velocity transducers
- accelerometers
- 4-20mA devices

Either individual ADC per channel for dynamic (vibration) signals or multiplexed configurations

Synchronous sampling circuitry and analysis relative to keyphasor to provide

- Harmonic amplitude and phase analysis for orders 1x, 2x, 3x, 4x
- Harmonic amplitude and phase for user-selected order
- Subsynchronous amplitude and frequency measurement
- Overall level
- Intra-harmonic amplitude

Spectral Banding mode of operation

Provide amplitude information for up to five user-selectable spectral bands plus overall amplitude

Digital input capability to define machine states such as

- Running / Stopped
- Onload / Offload
- Barring / Not Barring

Digital output capability for alarm indicators and watchdog

PROTOR Hardware

The PROTOR P4700 range of hardware has been designed for the monitoring and analysis of vibration and associated parameters within an industrial environment. The P4700 hardware seamlessly integrates with Prosig's existing PROTOR products for rotating machine vibration monitoring and protection.

The P4700 is designed to be mounted close to the signal source thus reducing expensive cabling costs. Communication to the P4700 is via standard TCP/IP Ethernet. For particularly harsh environments the P4700 may be mounted in an appropriately IP-rated enclosure for protection from excessive dirt and moisture. P4700 uses 24V DC power.

Summary

PROTOR is the most cost effective and efficient way of capturing, analyzing and reporting data from rotating plant. The PROTOR system protects your plant and provides a future-proof solution to health monitoring.

Dimensions	**Height 178mm (4U) x Width 448mm (19inch rack mounting) x Depth 361mm**
Power Requirements	**24V DC 150W or 6A @24V External rail-mount 110/220V AC to 24V DC power supply available as an option.**
Input channels	**Up to 32 channels per chassis Multiple chassis may be configured.**
Resolution	**16-bit**
Maximum Sample Rate	**20K samples/second per channel**
Input Frequency Range	**DC to 10KHz**
Input Coupling	**Programmable DC Direct , AC with 1Hz high pass filter.**
Transducer Excitation	**Programmable 24V DC power per channel.**
ICP® Transducer support	**4mA supply from 24v source**
Input Voltage	**Programmable +/- 24V, +/-10V +/- 1V +/- 100mV**
Input Impedance	**800 KOhm. Galvanic isolation available as an option.**
Maximum Common Mode Voltage	**±200V common mode compliance.**
Anti-aliasing Filter	**Programmable 8-pole Butterworth low-pass filter in range 200Hz to 20KHz.**
Phase matching	**Better than 1deg between channels. Phase compensation for filter delays performed.**
Tacho Input Range	**±24V**
Tacho Frequency Range	**0 to 120,000 RPM**
Tacho Conditioning	**Dedicated conditioning for up to 4 tachometer signals per unit. Programmable threshold, slope and re-trigger period.**
Speed Reading Accuracy	**Better than +/- 1RPM**
Synchronous Sampling	**Programmable synchronous sampling circuitry to provide 16,32,64,128 or 256 pulses per cycle.**
Constant Sampling	**Programmable constant rate sampling clock.**
Frequency Resolution	**Selectable FFT sizes of 128, 256, 512 or 1024**
Amplitude accuracy	**Accuracy of both AC and DC measurements referenced to full scale amplitude. Measurements are better than 2% fsd for amplitude and 2% in phase in all conditions apart from very low-speed or high rates of change of speed (> 50RPM/sec)**
Speed Resolution	**< 10RPM increments for speed change < 50 RPM/sec.**
AC/DC separation	**Circuitry allows DC (Gap) component and AC (Vibration) component to be measured simultaneously for displacement or proximity type transducers.**
Time Synchronisation	**Accepts synchronisation commands from PROTOR Host. Internal, battery-backed date/time storage.**
Indicators	**Front-panel LEDS for Power and Tacho trigger.**
Signal Inputs	**D-type sockets on back panel. Rail-mount screw terminals**
Power Fail Recovery	**The system is capable of re-booting and restarting normal operation following power failures and without user intervention.**
Diagnostic Functions	**Each data acquisition card within the system contains an onboard signal generator for fault diagnosis. Under software control, each channel on that card may be temporarily switched from reading its normal external input to reading the signal from the internal generator. The signal follows the same signal path as the normal vibration signal. The resultant waveform is analyzed by the system and compared to a table of expected results. Any deviations from expected within a certain tolerance are highlighted and reported to the System log.**

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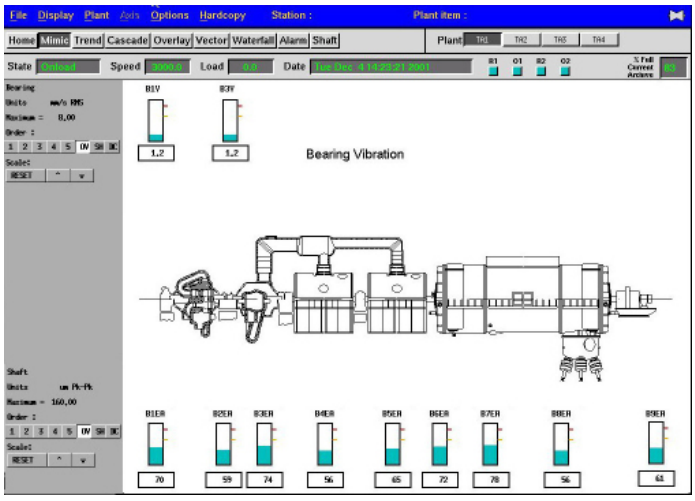
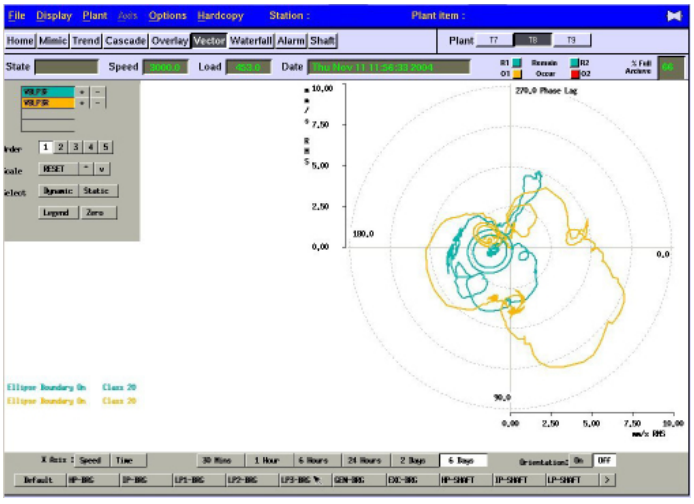
Some screenshots of the PROTOR system in action

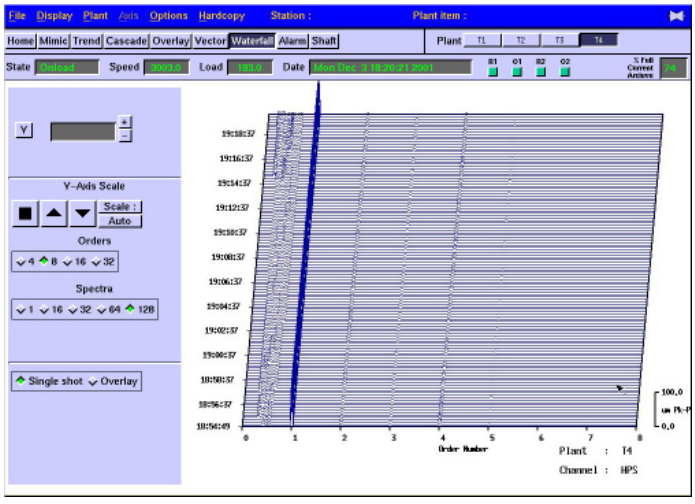
PROTOR "Home" Page



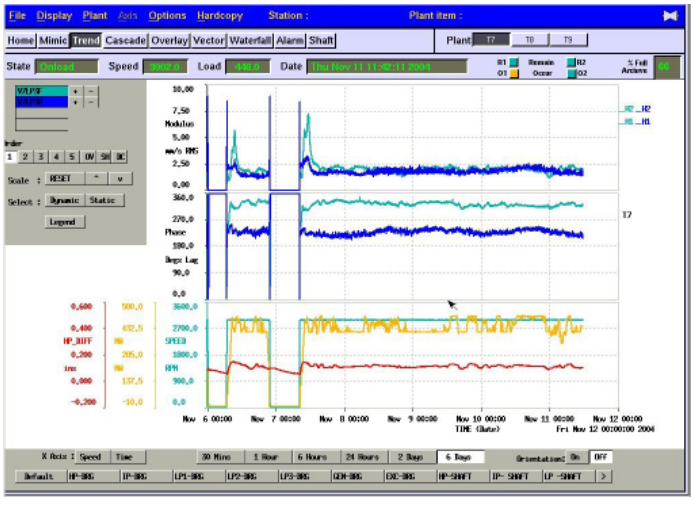
Mimic Diagram



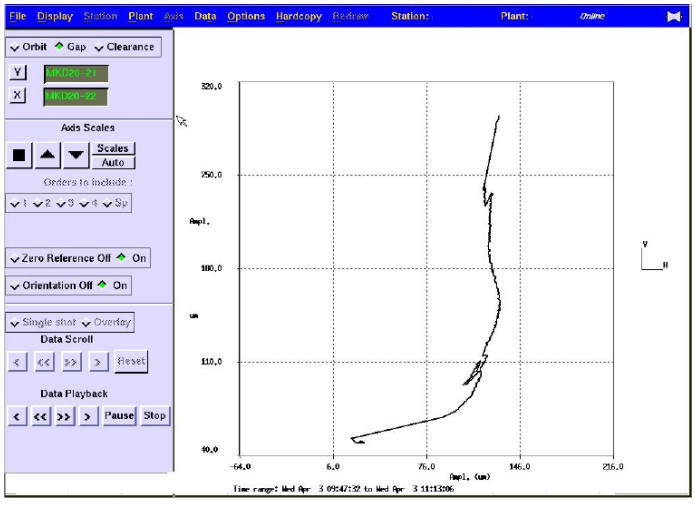
Vector Plot



Waterfall



Trend Plot



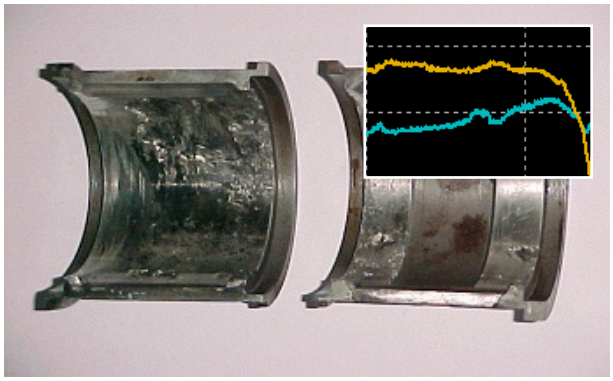
Shaft Gap

Some examples of PROTOR in action

PROTOR is used worldwide for the continuous monitoring of rotating machines such as steam turbines, gas turbines and auxiliary pumps and fans. PROTOR's continuous monitoring of the amplitude and phase of the main harmonics and sophisticated alarm processing means that it can be used to assist in early detection and diagnosis of vibration problems which if left untreated may cause damage and subsequent loss in revenue. The following are some example case studies where PROTOR was used...

Pilot Exciter Bearing Failure

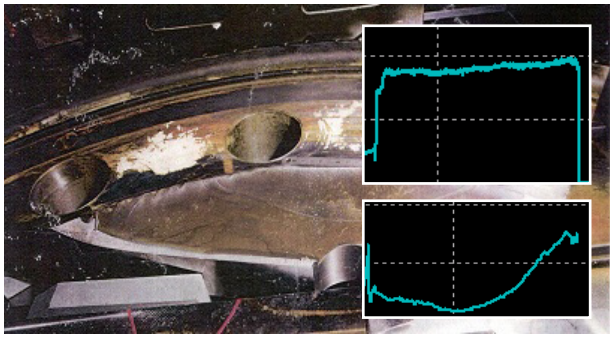
"This shows that a fall in vibration is not necessarily a good thing."



The failure was initially detected by a fall in 1st order vibration. Problem was confirmed by corresponding increase in higher harmonics. The PROTOR elliptical boundary alarms detect fall in vibration as well as rise. By early detection the bearing could be replaced without causing further more substantial damage.
Having detected and diagnosed a bearing failure the plant was either allowed to run to a convenient outage or quickly changed preventing secondary damage. Only the affected item needed attention.

Gas Turbine Rotor Disk Crack

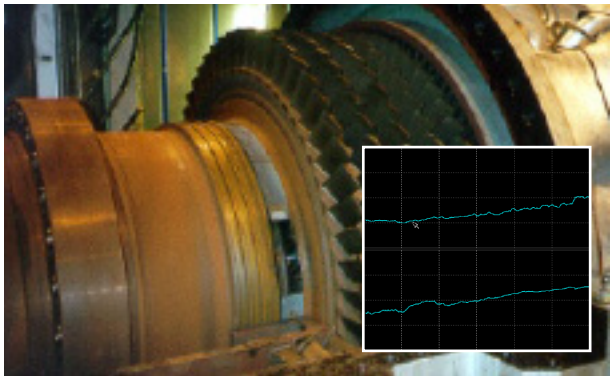
"In this case the vibration levels were not high enough to trigger conventional alarms. The fault was detected by vector change."



Disk crack seen as persistent vector change with initially small phase change.
After regular return to service underlying vector changed followed by exponential rise in vibration amplitude and change in phase.

Compressor Tie Bolt Failure

"Decisive, informed action reduced outage time and minimized lost revenue."



Slow rise in vibration with phase change
Vibration levels not high enough to trigger level alarms.
Early detection by vector gradient alarm meant machine taken out of service before catastrophic failure. Investigation revealed cracked compressor tie bolt

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PROTOR Mobile System

Lightweight
Rugged
Portable
Local & remote data access
Turbine & auxiliary monitoring
Wide range of fault detection
Realtime & historic data
Choice of data visualizations

PROTOR-Mobile is the ideal investigative tool for condition monitoring of rotating machinery. It provides the same extensive facilities as a standard PROTOR system but as a portable unit, rugged enough to withstand the typical power station environment.

PROTOR-Mobile provides high quality, high-speed data acquisition and analysis. Data acquired synchronous to a once per revolution tachometer signal to provide high accuracy harmonic and sub-harmonic measurements or time-based for slow speed conditions or where a tachometer signal is not available.

A standard signal conditioning module allows inputs to be taken from accelerometers, velocity or displacement probes. The system can provide 24V DC excitation for proximity probes and also supports IEPE transducers. Signal conditioning parameters such as gain, AC/DC coupling and anti-aliasing filter selection are programmable.

PROTOR-Mobile is a standalone unit. Access is provided either by standard monitor, keyboard and mouse ports or by Ethernet or by modem. Typically access will be via a Notebook computer running Windows and using an Ethernet connection. Connection may also be via an existing station network which would then provide local area connection even remote connection should Wide Area or VPN facilities be available. Using either connection PROTOR-Mobile may be configured and set to work, thereafter the system may be left unattended to collect and store data to its internal disk.

PROTOR-Mobile is available in two packages one supports up to 16 transducer inputs with two phase-reference or tachometer signals and the other supports up-to 32 inputs and four phase-reference signals. The inputs may be configured as either vibration signals (dynamics) or plant process parameters (statics). Each of the phase reference signals may be associated with an 8-channel signal group. This provides great flexibility in configuring the system for a number of different applications. In the simplest case the system may be configured to monitor a single machine using all channels relative to a single tacho. Alternatively it is possible to monitor multiple machines each with their own 8-channel blocks and individual phase-reference signals. The total channels allocated to each machine can be configured as any combination of dynamic and static channels.

PROTOR-Mobile provides the same intuitive Graphical User Interface as used by the standard PROTOR system. This simply allows the user to select the type of display and the channels to be displayed by pop-up and pull-down menus using 'point and click' selection and the graphical selection of the data to be displayed.

PROTOR-Mobile allows screen shots to be easily cut and pasted into standard Windows software and data to be easily exported.

PROTOR for Shaft Displacement Measurements

Shaft displacement is an important vibration measurement for rotating machines. Shaft displacement is usually monitored by non-contact shaft displacement probes such as eddy-current probes. These probes produce a voltage proportional to the distance of the shaft surface relative to the tip of the probe. For maximum benefit, ideally two shaft displacement probes will be fitted to measure the displacement in both the horizontal and vertical directions.

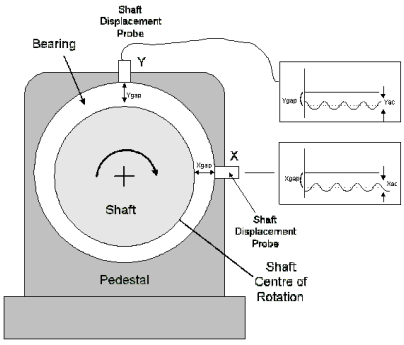


Figure 1: Eddy Current probes

The diagram opposite shows a typical arrangement.

This shows that the vibration signal from shaft displacement probes contains both AC and DC components. The DC component is a measure of the overall distance of the shaft from the probe, this is called the gap. The AC component is measure of the movement of the rotating shaft about its central position. In general the DC component is large (typically -15V) with a much smaller AC component. The PROTOR data acquisition hardware includes dedicated signal conditioning which allows both the AC and DC components to be measured with high accuracy using only a single input channel.

Shaft Vibration

The AC component is usually analyzed with respect to a 'once per revolution' tachometer signal to provide measurements which are an indication of the movement of the shaft on a rotational or 'per cycle' basis. This provides information which is used to detect phenomena such as unbalance, misalignment, rotor bends, cracks and so on. For example, assume a rotor, supported by two bearings, has a bend or bow as shown below (greatly exaggerated for display purposes then the displacement time history would be sinusoidal.

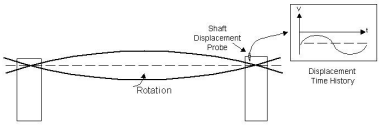


Figure 2: Rotor supported by two bearings

The PROTOR system measures the AC signal for displacement probes and performs frequency analysis on the signal with reference to the tachometer signal to identify the Overall displacement on a cyclic basis together with its constituent components such as the 1st, 2nd, 3rd, 4th and higher harmonics (both amplitude and phase), sub-harmonic (amplitude and frequency) and intra-harmonic components. These measured components are collected and stored on a regular basis and made available for real-time mimic diagrams, trend displays, vector diagrams, alert processing and also for historical analysis.

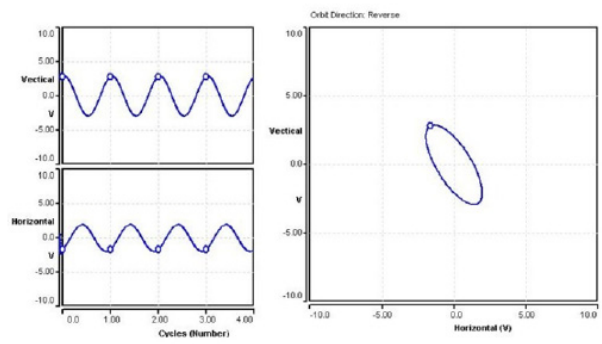
Transducer Orientation

To be of most benefit a pair of perpendicular shaft displacement probes are often used to allow measurement of the movement in both the vertical and horizontal directions.

NOTE: It is often not physically possible to mount probes in the actual vertical and horizontal planes. The PROTOR system configuration allows the actual transducer mounting position to be defined. It can then mathematically combine the contributions of a pair of probes to estimate the actual displacement in the true vertical and horizontal planes.

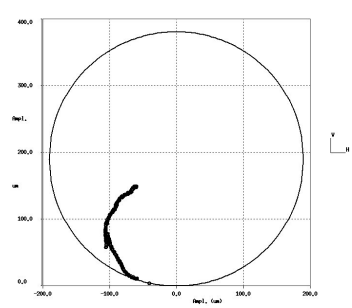
Orbit Plots

Two perpendicular shaft displacement signals may be either directly measured or determined through the orientation software. When two such signals are available then PROTOR is able to display the data in the form of a shaft 'Orbit'. An Orbit display is effectively a dynamic display of the movement of the centre of the shaft. Within PROTOR it is possible to display the 'filtered' orbits, that is the individual contributions from each of the measured orders. Alternatively you can select which orders to include in the orbit display.



Shaft Gaps

As mentioned above the signal from a shaft displacement probe also has a DC component which is proportional to the average gap between the probe tip and the shaft surface. The PROTOR system also measures and logs these components and makes them available for trending and display. If bearing clearance information is available then this may be entered and the movement of the shaft shown relative to the clearance.



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PROTOR Signal Conditioning for High-Common mode and Isolation

For monitoring systems in an industrial environment special care and attention is required for both signal cables and input signal conditioning circuitry. Typical problems in this environment include long cable runs and cable routes in the proximity of high voltage sources can cause noise induction and large ground potential differences to exist. The effect of differing ground potentials between the signal source and the measurement system is of particular interest. For monitoring systems in a clean or laboratory environment then the signal source and measurement system are close together and ground or earth differences are negligible and so can be ignored.

The following notes describe some of the concepts and terminology related to these phenomena and describe ways in which these effects can be minimized by careful selection of signal cabling and signal conditioning components.

Single-Ended Inputs

With single-ended inputs a single connection is made from the signal source to the data acquisition system. The measurement made is the difference between the signal and the ground or earth. In order for the measurements to be accurate then we must ensure that the signal source is grounded (earthed) and the signal source and the acquisition system's earth have the same value. In most practical or industrial applications the ground or earths may be significantly different between the transducer source and the measurement system. Single-ended inputs are also sensitive to noise errors, in particular for long cable runs.

Differential Inputs

One way to eliminate this problem is to use differential inputs to a differential amplifier. With differential inputs, two connections are made from the signal source to the measurement system. The differential amplifier gives the difference between the two inputs, meaning that any voltage common to both wires is removed. Therefore, providing the difference in earth potential between the source and measurement system is not too large, then it does not affect measurement accuracy.

However in a number of cases especially in industrial environments where the signal source may be a long distance from the measurement system or when 'floating' inputs are used (which have no ground reference) then the difference in grounds may be significant. In these cases we need to take account of the voltage compliance range of the input amplifier and if necessary use specialist components or circuitry which removes or rejects this voltage difference.

Common-Mode

The common-mode voltage is defined as the voltage that is measured with respect to a common-mode reference point and is present on (or common to) both sides of a differential input signal. Most frequently, the common-mode reference point for a complete system is the system earth or ground. Problems arise if this common-mode voltage exceeds voltage compliance of the signal conditioning input circuitry, typically < 15V.

A solution is to use an instrumentation amplifier with a high Common-Mode Rejection Ratio (CMRR). The CMRR is a measure of how well the amplifier rejects the common-mode voltage. An ideal amplifier will have a CMRR of infinity. In practice, high-common mode amplifiers have a CMRR of around 80 to 90 dB. The higher the rejection ratio the better. The other important factor is the common mode range. This is the maximum common-mode voltage with which the amplifier can cope. Typical Common Mode Range values are +/- 200V. There are cases where extreme common-mode voltages may exist which may require further conditioning. In such cases Isolating amplifiers may be required.

Isolation

In some situations, a number of monitoring systems may 'share' signal inputs from a transducer, in this case care must be taken to ensure that the system does not affect the signal in anyway. In this case isolation amplifiers should be used such that electrical isolation is provided between the measurement system's input and its measurement circuitry. Such devices pass the signal from its input to the measurement device (ADC) without a physical connection by using transformer, optical, or capacitive coupling techniques. This ensures that no possibility of electrical current flowing from one measurement system to another.

PROTOR Solutions

As standard all PROTOR system are provided with high-common mode signal conditioning. For the PROTOR-4 range of hardware the programmable P4751 8-channel module provides the high-common mode characteristics.

Galvanic isolation may also be provided as an option. For PROTOR-4 the software programmable P4761 card is available.

PROTOR for auxiliary machine monitoring

The use of the PROTOR system for monitoring vibration from large rotating machines fitted with fluid-filled journal bearings such as steam or gas turbines is well understood. Vibration from these components generally falls within the main harmonics or orders of the shaft rotational speed such as 1st, 2nd 3rd or 4th harmonic. Some energy may also exist below the 1st order, called the sub-synchronous component. Most energy exists below 1KHz and so standard displacement probes or velocity transducers are generally fitted. The PROTOR system collects this data in amplitude and phase form, relative to a 'once-per-revolution' phase reference signal, as standard and allows data to be displayed in real-time as mimic diagrams, trend plots, orbit and vector displays.

Less well known is the PROTOR system's ability to effectively monitor auxiliary items of plant such as pumps or fans. This includes rotating machines with gearboxes, rolling-element bearings, impellers and dual shaft machines. For these types of machine the vibration spectra may contain information over a wide range of frequencies that may be related to gear-mesh frequencies for gearboxes or inner or outer race frequencies for rolling element bearings. The following features are provided as standard within PROTOR and the PROTOR hardware for auxiliary plant item monitoring is exactly the same as that used for main turbines and so standard spares cover all items.

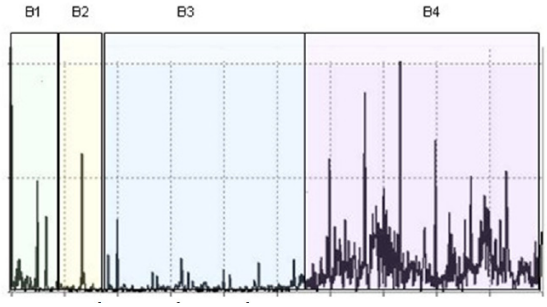
High frequency analysis

One major difference when monitoring vibration information for some auxiliary items compared with standard steam or gas turbines is the ability to monitor high-frequency content. As mentioned above, for turbines most vibration information is within the 0 to 1KHz frequency band. For high-speed auxiliary machines with gearboxes or rolling-element bearings then some frequency components may be much higher, possibly up to 10KHz. For these machines accelerometers will generally be fitted. The PROTOR P4700 system supports accelerometers as standard and will also provide a constant-current source for IEPE transducers under software control. The P4700 system contains a programmable low-pass filter and allows sampling in excess of 20K samples per second per channel.

Multi-machine configuration

One main advantage of the PROTOR system for this type of analysis is the flexibility of the system hardware and configuration. A number of auxiliary plant equipment such as boiler feed pumps or FD and ID fans contain components running at different speeds such as a motor and a pump or a motor and a fan. A PROTOR P4700 data acquisition unit can take in up to four separate 'once per revolution' speed or phase reference signals and each 8-channel data acquisition card may be associated with any one of these speed signals.

In this example we have a LP and HP turbine each with their own phase reference signal. Signals from the LP and HP units are analyzed relative to their own phase reference. Signals from the gearbox are 'shared' and analyzed twice, once relative to the LP tacho and then relative to the HP tacho.



Spectral band analysis harmonic configuration

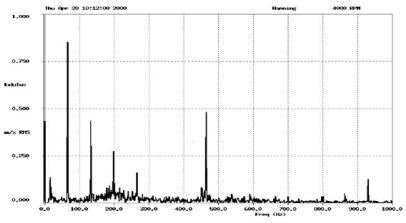
Another feature of the PROTOR system is the ability to configure the system to analyze and collect specific harmonics. For example, for a Gas Circulator within a nuclear power station one primary frequency component is related to the number of impeller blades, in this case 31. For this case PROTOR was configured to measure the 31st harmonic as standard. This component is then available alongside the other standard harmonics for display, trending and alarm checking.

Spectral band analysis

Another feature of PROTOR is the ability to configure spectral bands. These frequency bands may be set by user for a particular machine and can be set dependent on the machine configuration around particular frequencies of interest such as gear-mesh frequencies or blade-passing frequencies. This method is used when the frequency content is well known and understood. Alternatively when the frequency content is not well known, the bands may be set for general zones of interest, say a low-frequency zone (below running speed) , a running speed zone, a general vibration zone (encompassing 2nd, 3rd and 4th harmonics) and a high-frequency zone.

Gearbox ratios

PROTOR also handles situations where only a single speed or phase reference signal is available. For example, with some gearboxes a single tachometer signal positioned on one side of the box is often the only speed reference available. In this case it is possible to define the gearbox ratio and to specify the channels associated with either side of the gearbox. For channels where the speed signal is available then normal harmonic analysis is performed. For channels on the other side of the gearbox then the speed measured by the available tachometer signal is factored by the gearbox ratio, the resultant speed is then used to determine the expected harmonic locations on this channels.



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