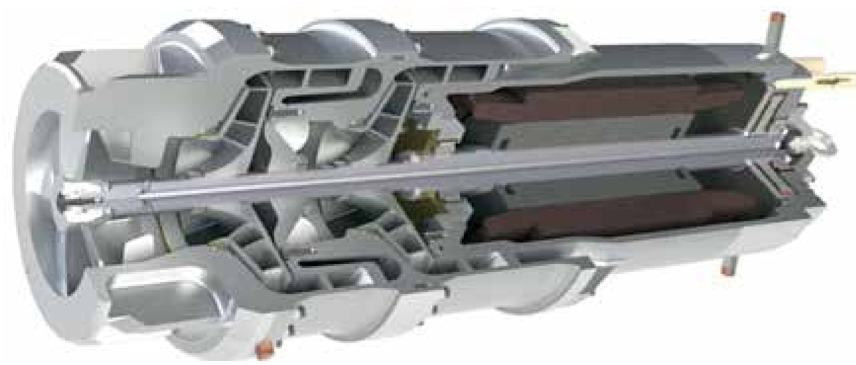
Application Guide for the Condition Monitoring of Cryogenic Pumps



Nikkiso Cryo Pump Courtesy of Nikkiso Cryo Inc.

Table of Contents

application note

Abstract
This application note contains recommendations for the selection and installation of GE's Bently Nevada transducers, monitoring and protection systems, and asset condition monitoring systems for cryogenic pumps. Based on each machine's design, these recommendations may need to be customized. This document also addresses common failure types and proposes applicable solutions. Continuous collection and trending of the vibration and other parameters using a machinery management system such as GE's Bently Nevada System 1* optimization and diagnostic software is highly recommended. Use of these tools will increase the ability to diagnose problems and analyze the machine's performance.

1 Introduction

The purpose of this document is to help the Bently Nevada product line's sales managers and Field Application Engineers (FAEs) with customer discussions about selecting a condition monitoring and protection system for their cryogenic pumps.

NOTE: Machinery protection is implemented when vibration (or other) instruments are installed permanently onto a machine and connected to a dedicated monitoring and protection system. The protection system has alarm setpoints, which are set by the machinery OEM or the end user to automatically raise an alarm when the predetermined alarm level is reached. The system has alarm relays for alert and danger conditions that can initiate an automatic shutdown or trip of the machine. Alternatively, instructions to shut down the machine may be acted upon by an operator when an alarm occurs. Machinery protection is necessary and valuable since it may prevent or minimize machine damage and consequential losses in the event that a sudden machinery or process malfunction occurs.

"Cryogenic pump" is a generic name for the large variety of pumps that are used to move liquefied gases such as liquefied natural gas (LNG), polymer processes and air separation units. Because cryogenic pump construction differs by design, failure modes and criticality may have considerable variability, and no single solution will suit all designs. The most common pump types that are used in this market space are:

- Hermetic integrated centrifugal motor pump with rolling element bearings (REB) (see picture at right)
- Hermetic integrated centrifugal motor pump with journal bearings
- Reciprocating pumps

The liquefied gas typically acts as the lubricant in the bearings. It is not uncommon that within the same machine train some of the bearings are roller element bearings (REBs) and some are journal bearings.

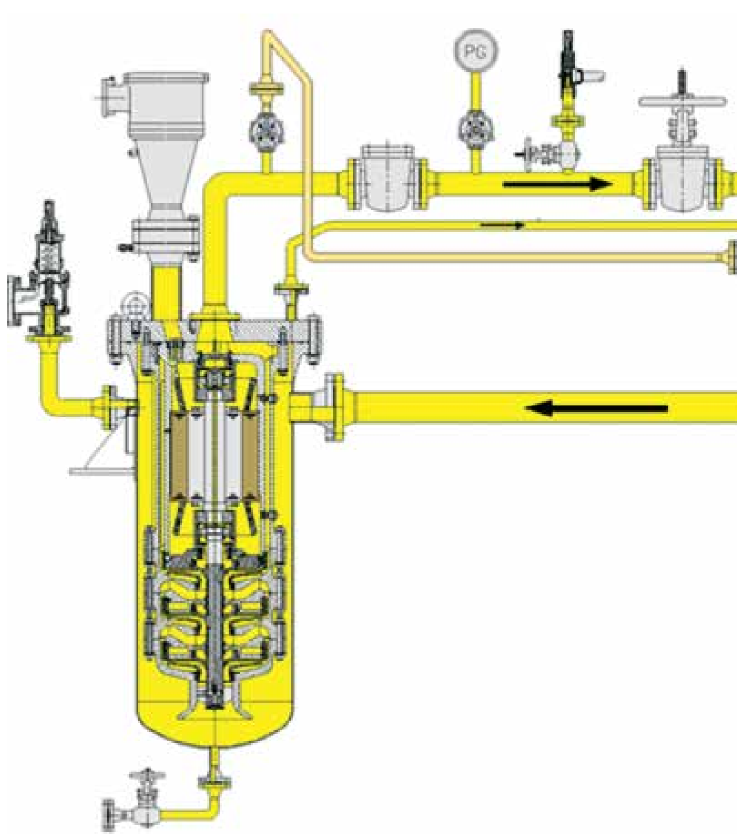


Image courtesy of Borealis, Finland

The InTank architecture usually is used for the booster pumps, which are located in the tank of liquefied gas. Note that for these pumps, the electric motor is submerged into liquefied gas, which also provides bearing lubrication. No seals are needed, which is a major reason for this design.

The vessel architecture normally is used for the process pumps, which push the gas to the heat exchanger and then to the gas pipeline. Note that for these pumps, the electric motor is submerged into liquefied gas, which also provides bearing lubrication. No seals are needed – again, a major reason leading to this design.

The cold temperatures – from -44 ° C (-44 ° F) for propane to near absolute zero – that result from liquefaction of the various gases often make it impossible to use conventional sensors and cables. In this document, third-party sensors that can be used are presented, as well as a method that allows for the use of our existing casing sensors.

NOTE: Since these applications involve operation with liquefied gas, such as natural gas or propane, properly specified product Hazardous Area Approvals is an essential part of the product offering.

Following are typical liquid gas temperatures, although the actual temperatures may vary somewhat since most liquefied gases contain a mixture of gases:

Butane	-0.5 ° C (31.1 ° F)
Propane	-42.22 ° C (-44 ° F)
Natural gas	-160 ° C (-260 ° F)
Oxygen	-183 ° C (-297 ° F)
Nitrogen	-210 ° C (-346 ° F)
Hydrogen	-252.87 ° C (-423.17 ° F)
Helium	-269 ° C (-452.2 ° F)

2 Common Failure Modes

2.1 Hermetic Motor-Pump with Rolling Element Bearings

The main problem with this type of machine train is rolling element bearing failure. If not detected early enough the consequent failures will be introduced to the motor and/or pump sealing, making repair work much more time consuming and costly. Since liquefied gas is an imperfect lubricant for bearings, it is likely that bearing faults may take place much earlier than with similar oil-lubricated pumps operating in a cleaner environment and warm temperatures.

2.2 Hermetic Motor-Pump with Journal Bearings

The main problem with this type of machine train is excessive shaft vibration due to increased clearance on the bearings, possibly accelerated by the poor lubrication characteristics of the liquefied gas. If not detected early enough, the consequent failures will be introduced to the pump sealing, making repair work much more time consuming and costly. Since liquefied gas is an imperfect lubricant, it is likely that bearing wear may take place much earlier, resulting in increased wear and increased bearing clearance.

2.3 Reciprocating Pumps

Please refer to GE's Bently Nevada Best Practice document: Protecting and Managing Reciprocating Diaphragm Pumps [1].

3 Monitoring and Protection

Vessel-type pumps usually do not have transducers mounted at each bearing location. This makes the detection and diagnosis of a failing bearing very difficult. This is especially true for bearings located furthest from the sensor.

2300 Series system

3500 Series system

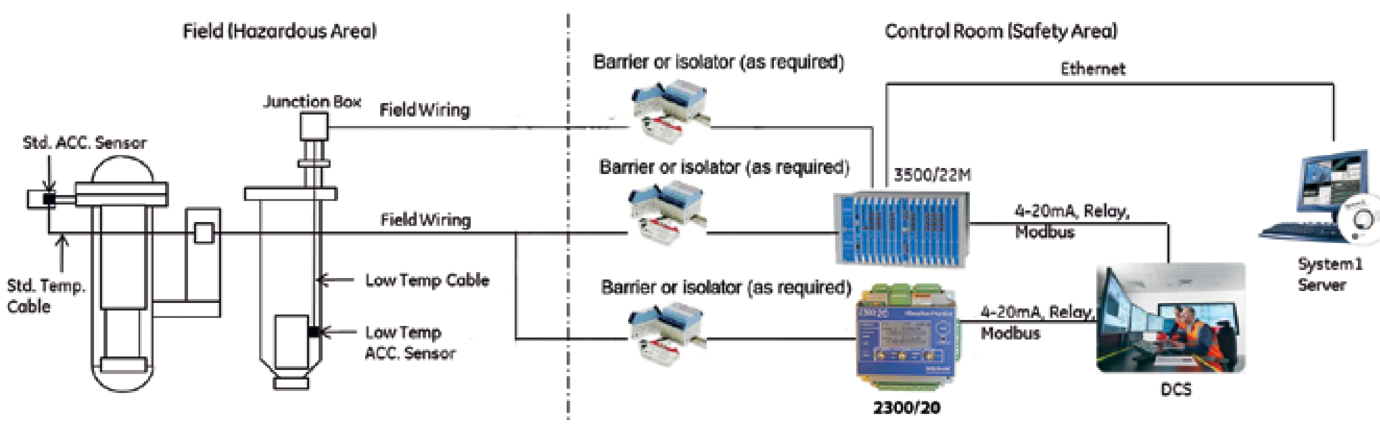
3.1 Hermetic Motor-Pump with Rolling Element Bearings

The following shows general system architecture for cryogenic machine monitoring and protection.

3.1.1 Online Continuous System

Customers requiring online continuous monitoring and relay protection should use either the Bently Nevada 3500 Series machinery monitoring system, the Bently Nevada ADAPT 3701 product family or the Bently Nevada 2300 vibration monitor series.

Online Continuous Solution

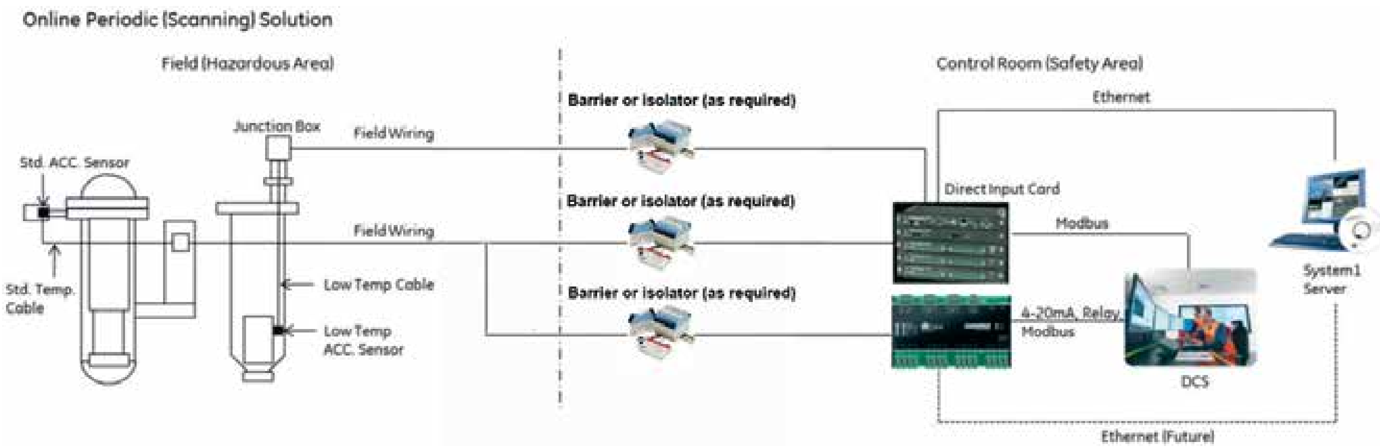


NOTE: The Bently Nevada 2300 vibration monitor series is a recommended replacement for the Bently Nevada 1900 Series machinery asset protection system.

NOTE: Since these applications involve operation with liquefied gas, i.e. natural gas, propane, etc., properly specified product Hazardous Area Approvals is an essential part of the product offering. For additional information on Hazardous Area requirements see GEA31966 Hazrd Areas App Guide.pdf or contact GE Bently Nevada Technical Support in Minden.

3.1.2 Online Periodic (Scanning) System

Trendmaster Pro is recommended for customers requiring online periodic monitoring but not requiring relay protection.



NOTE: Since these applications involve operation with liquefied gas, i.e. natural gas, propane, etc., properly specified product Hazardous Area Approvals is an essential part of the product offering. For additional information on Hazardous Area requirements see GEA31966 Hazrd Areas App Guide.pdf or contact GE Bently Nevada Technical Support in Minden.

3.1.3 Casing Transducers

In order to detect roller element bearing (REB) problems in the early phase, an accelerometer is the recommended sensor. Use of high frequency techniques, either high pass filtered acceleration peak value or enveloping (demodulation) peak value, will give the required indications of REB deterioration. The challenge is to get the accelerometers installed on a place where reliable vibration from the REBs can be observed. There are two ways to do this:

Use a PCB 351M31 or PCB351M34 accelerometer designed for low temperature applications. Refer to documents #42394 for PCB 351M31 and #47405 for PCB 351M34. The sensors will be installed on the casing of a cryogenic pump, as near to the bearings as possible.

NOTE: Depending on machinery configuration (design, installation, location, etc.), cryogenic motor/pump trains may produce ESD (electrostatic discharge) and/or cavitation. These electrical and mechanical disturbances may be observed as spiking on the vibration transducer's output signals. These spikes will affect outputs of our monitoring system, which may cause fault alarms. Therefore, advance consideration on alarm logics and time delays is highly recommended whenever applying these sensors to a cryogenic pump solution.

Use standard Bently Nevada accelerometers from GE, such as AM3100T2-Z2 and 330400. The installation of the sensor is done at the end of a metal measurement pin, which is long enough to pass the ice covering the pump and is firmly screwed to the cryogenic pump casing (see picture). This method has proven to work in practice through internal case studies.

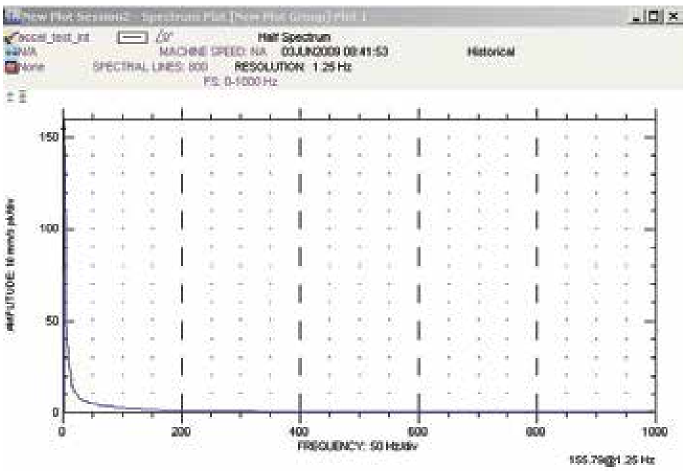
Image courtesy of Borealis, Finland

For REB condition monitoring purposes, the high frequency acceleration signal is the most important measurement, but other vibration readings also should be considered. A direct overall velocity measurement may be used for protection and to acquire dynamic data, if available, to help manage the machine.

If only velocity measurements are available, the recommended best practice is to configure the maximum frequency of the velocity spectra at 2000 Hz. This is a good compromise for detection of the components related to unbalance, misalignment, blade pass and bearing fault frequencies at an acceptable resolution (remember: only 800 lines are available for asynchronous sampling). These units normally rotate at 3000 rpm.

It is very important to know that in many cases the cryogenic sensors do not behave perfectly, and produce several high amplitude spikes in the direct trends (this phenomenon is especially evident at some particular conditions, such as low flow rate and/or low level in the tank).

When an excessively high amplitude event occurs, the corresponding spectra may show the "ski slope" pattern, which is clearly indicative of a bad reading.



Spectral plot showing "ski slope"

A "ski slope" signal is an artefact normally caused by overloading or saturation of the accelerometer sensor or monitor channel. The first spectral line reported in the spectral graph (see above 155.79 mm/sec @ 1.25 Hz) is very large and is unrelated to any physical vibration. This artefact invalidates the other frequency content in the graph.

Common reasons for the overload are incorrect mounting of the sensor, intermittent wiring, electrical interference, a large rapid temperature change or a very high vibration at a particular frequency exceeding the transducers' vibration range.

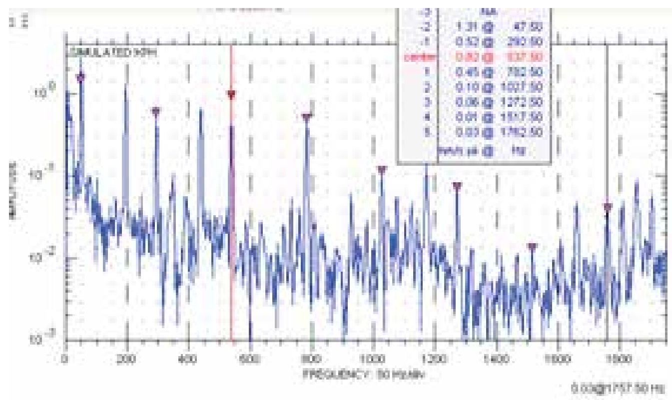
Sensor challenges that can greatly inhibit proper machine diagnostics are:

- Spiky signal response without sensor failure after time in service
- Spiky signal response with sensor failure
- Sensor failure immediately after the unit is put in service (may be not qualified for the service)

Thus the pump sensors must be properly qualified for the application, properly installed and properly maintained and monitored. An analysis tool for the sensor health is monitoring the bias voltage of an IEPE (integrated electronic piezoelectric accelerometer), which can be accomplished by setting the rack configuration to Acceleration 2 rather than Acceleration. Acceleration 2 allows bias voltage measurement and tracking.

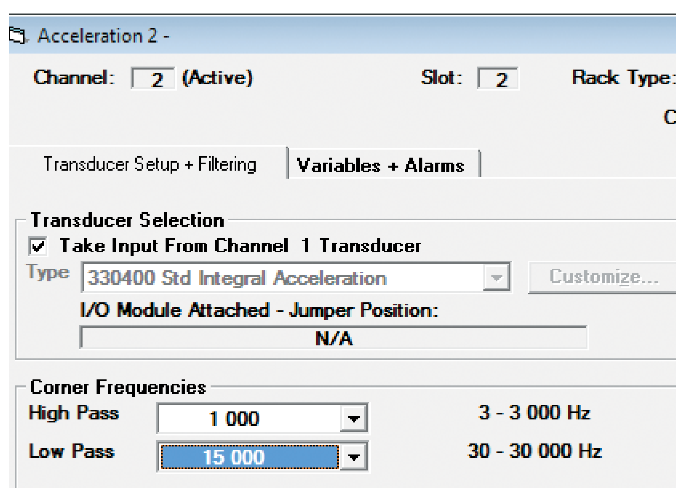
An accelerometer bias voltage that is unstable or contains spikes is a clear indication of a malfunctioning accelerometer sensor, so the data taken under those circumstances is of limited or no value for diagnosing pump problems. The cause of the unstable bias voltage needs to be determined and corrected to reestablish proper monitoring and protection.

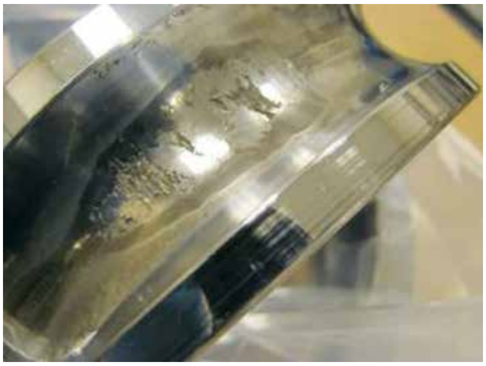
Example of bearing failure detection on cryogenic pump:



Spectrum of a damaged bearing

The logarithmic spectrum coming from the sensor located on the motor (top sensor) shows a family of sidebands at 245 Hz, the inner ring fault frequency. This corresponded to damage occurring on the inner ring of the motor bearing. When the pump was removed from service and inspected, the damage was confirmed.





Bearing #1 - Inner ring raceway
with prominent spalled area

Bearing #1 – inner ring raceway
showing severe wear path near the spalls

3.1.4 Monitors

The selection of the appropriate monitoring system will depend upon the customers' need and their condition monitoring practices. If protection is required, then either the Bently Nevada 3500 Series machinery monitoring system or the Bently Nevada 2300 vibration monitor series can be used.

If the 3500 Series is in use, it is recommended that one acceleration signal is used on two channels, with the first channel integrated to velocity and the second channel dedicated to bearing problem detection using the setup shown.

If the 2300/20 monitor is used, at least two readings should be gathered from each sensor – one direct velocity and one high pass filtered acceleration.

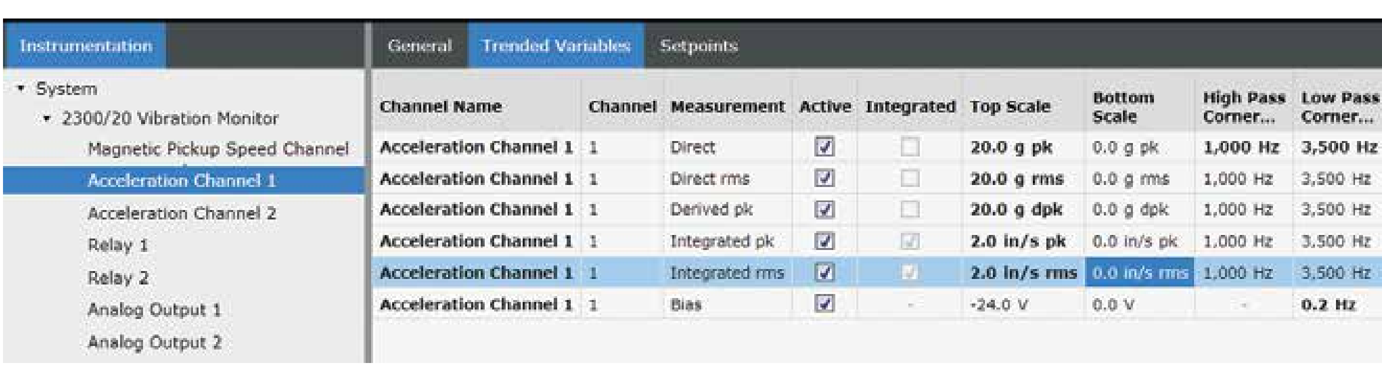
If only monitoring is required, then scanning monitors, **DSM, VbOnline, Essential Insight.mesh wireless (EI.Mesh)** and **AnomAlert** all can be applied. A **Bently Nevada SCOUT Portable Vibration Analyzer** from GE can be used as a supportive method, but it should not be the only option since bearing failures on cryogenic pumps may develop quite rapidly. Also, temporarily mounted accelerometers do not always give a reliable early indication of bearing problems, while permanently installed sensors provide a more reliable and consistent measurement.

3.1.5 Condition monitoring with motor current (AnomAlert)

AnomAlert motor anomaly detectors continuously identify existing and developing faults on electric motors and their driven equipment. AnomAlert uses an intelligent, model-based approach to provide anomaly detection by measuring the current and voltage signals from the electrical supply to the motor. Since it doesn't require any sensor installation on the motor or associated load, AnomAlert is a suitable condition monitoring approach for hermetic or submerged cryogenic service pumps, compressors, and similar motor loads where vibration sensors or other direct measurement sensors cannot be installed.

Bently Nevada AnomAlert motor anomaly detection system from GE

This system is applicable to 3-Ø AC, induction or synchronous, fixed or variable speed motors. AnomAlert provides both mechanical (unbalance, misalignment, and roller bearings, for instance) and electrical (loose windings, short circuits, etc.)



Instrumentation | General | Trended Variables | Setpoints

- System
  - 2300/20 Vibration Monitor
    - Magnetic Pickup Speed Channel
    - Acceleration Channel 1
    - Acceleration Channel 2
    - Relay 1
    - Relay 2
    - Analog Output 1
    - Analog Output 2

Channel Name	Channel	Measurement	Active	Integrated	Top Scale	Bottom Scale	High Pass Corner...	Low Pass Corner...
Acceleration Channel 1	1	Direct	☑	☐	20.0 g pk	0.0 g pk	1,000 Hz	3,500 Hz
Acceleration Channel 1	1	Direct rms	☑	☐	20.0 g rms	0.0 g rms	1,000 Hz	3,500 Hz
Acceleration Channel 1	1	Derived pk	☑	☐	20.0 g dpk	0.0 g dpk	1,000 Hz	3,500 Hz
Acceleration Channel 1	1	Integrated pk	☑	☑	2.0 in/s pk	0.0 in/s pk	1,000 Hz	3,500 Hz
Acceleration Channel 1	1	Integrated rms	☑	☑	2.0 in/s rms	0.0 in/s rms	1,000 Hz	3,500 Hz
Acceleration Channel 1	1	Bias	☑	-	-24.0 V	0.0 V	-	0.2 Hz

anomaly detection as well as electrical parameters such as voltage and current imbalances and power factor. In addition, it can detect changes in the load the motor is experiencing due to anomalies in the driven equipment or process such as cavitation or plugged filters and screens.

Although AnomAlert can provide warning of the following potential failures and provides some key electrical parameters relevant with motor performance and condition, it does not provide detailed diagnostic capabilities. In addition, timing of failure detection may not be early enough when compared to other direct condition monitoring technology (i.e., bearing failure).

Mechanical Faults:	Electrical Faults:	Electrical parameters
• Unbalance	• Rotor/stator	• Vrms (3 phases)
• Misalignment	• Loose windings	• Irms (3 phases)
• Bearings (REB) • Coupling	• Short circuits • Insulation failure	• Voltage imbalance • Current imbalance
• Loose foundation		• Power factor
• Loose parts		• Reactive power
		• Active power
		• Total harmonic distortion
		• 3, 5, 7, 9, 11, 13 Harmonic

3.2 Hermetic Motor-Pump with Journal Bearings

For journal bearing solutions, GE recommends proximity transducers as the primary solution. GE has provided cryogenic proximity sensors for years to the aerospace industry and to some cryogenic pump manufacturers, but the cost and difficulty of installation of a proximity probe within the cryogenic pump has precluded their use.

Because seismic transducers are not a perfect solution for journal bearings, either, it is currently recommended that the primary solution for hermetic motor-pump with journal bearings is **AnomAlert**.

For more details about AnomAlert, refer to section 3.1.5.

3.3 Reciprocating Pumps

Refer to GE's Bently Nevada Best Practice document: Protecting and Managing Reciprocating Diaphragm Pumps.[1]

4 Part Numbers

4.1 P/Ns for Hermetic Motor-Pump with Rolling Element Bearings

Bently Nevada 2300 vibration monitor series based:	
2300/20-02	Monitor
AM3100T2-Z2	Accelerometer with measurement pin
330400-XX-05	Accelerometer with measurement pin
PCB351M31/M34	Accelerometer without measurement pin
See sensor data sheet	Cable
Bently Nevada 3500 Series machinery monitoring system based:	
3500/42-09-02	Monitor
330400-XX-05	Accelerometer with measurement pin
PCB351M31/M34	Accelerometer without measurement pin
See sensor data sheet	Cable
See S1 data sheet	SW
DSM based:	
149744-02-01-05-00-00-00-02-00	Monitor
200350-XX-00-01	Accelerometer with measurement pin
See sensor data sheet	Cable
See S1 data sheet	SW
EI.Mesh based with measurement pin:	
100M3472-01 indoor starter package	Package contains all necessary components. If 16 channels is not a good fit, see the EI.Mesh data sheet for other options
VbOnline based:	
ALCO0535/6/7/8	Monitor, 4/8/12/16 channel
AM3100T2-Z2	Accelerometer with measurement pin
NA from Commtest data sheet	Cable
See Commtest data sheet	Ascent SW

4.2 P/Ns for Hermetic Motor-Pump with Journal Bearings

As mentioned in section 3.2, AnomAlert is the preferred condition monitoring solution for this type of pumps. For detailed P/Ns, please refer to the AnomAlert data sheet.

4.3 Reciprocating Pumps

Regarding reciprocating pumps, please refer to GE's Bently Nevada Best Practice document: Protecting and Managing Reciprocating Diaphragm Pumps.

5 Software

The following Bently Nevada Software products are available to be used on cryogenic pump monitoring applications, depending on customer requirements.

5.1 Bently Nevada System 1* Classic Software (System 1) from GE

System 1 software is a condition monitoring software platform for real-time optimization of equipment and selected processes, condition monitoring, and event diagnostics.

5.2 SmartSignal

SmartSignal predictive-diagnostic software provides exception-based notifications of developing problems. The software excels at process and vibration data correlations, high true positives, and prioritized early warnings. Credible information on the apparent causes of impending problems is included, along with prioritizations, key tags, and values. By combining vibration and process data, SmartSignal brings advance notification of machinery issues so customers can take necessary actions without unexpected shutdown.

6 Services

The following are GE Bently Nevada's service offerings for Cryogenic Pump monitoring.

6.1 Installation & Commissioning

For customers to get the most out of the system, the following initial services are strongly recommended.

Description
Project Management and Documentation 3500 – DSM solution
Installation and Configuration of System 1 in house
Integration of Process data points (price per point)
Basic configuration of DSM System in house
Basic configuration of 3500 System in house
On Site commissioning, Site Acceptance Test, Configuration changes to as build
Training up to 12 people on site
System 1 basic training (2 days)
DSM (Trendmaster PRO) training 2 days
3500 Operation and Maintenance training 3 days

It should be noted that due to construction issues, the cryogenic pump machine train often is delivered to the customer site a couple of years before the actual production begins. Therefore, extra attention should be paid to the commissioning and fine tuning of the system.

6.2 Bently Nevada product line Supporting Services Agreement (SSA)

To meet production commitments while lowering operating and maintenance expenses, customers must get the most out of their products. GE will work with them to accomplish that goal by properly maintaining their system and helping ensure it is being used to its full potential. A service agreement for the Bently Nevada product line provides customized care designed to maximize the value of the customer's investment in asset condition monitoring technology.

7 References

[1] http://www.slideshare.net/chris_engdahl/bently-nevada-reciprocating-diaphragm-pump-best-practices

1631 Bently Parkway South, Minden, Nevada USA 89423
Phone: 1.775.782.3611 Bently.com