Mechanalysis (India) Ltd

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condition management solutions

Engineering the Environment

Taking you Further

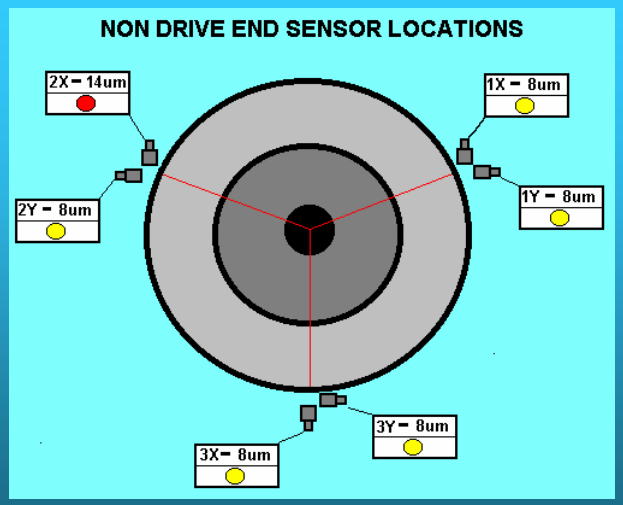
Stator End Winding Monitoring Development in India

CONTENTS

Stator End Winding for Power Generation

Fossil Fuel Power Station

Hydrogen Cooled Generator



Sensor Matrix on End Winding

Gas Fired Power Station

Stator End Winding Monitoring Prime Objectives

1. To maintain power generation
2. To prevent insulation breakdown, failure and possible combustion
3. To monitor the condition of the generator windings for rigidity
4. To indicate maintenance improvements when windings are reconditioned or ‘tightened’

The Problem

Cleaning the Generator Windings before mounting sensors for retro-fit

- End windings protrude from the stator and hence are most subject to bending stresses
- Excessive vibration and thermal cycling weakens insulation; causes bar fractures
- More modern installations are hydrogen cooled which is an inherent explosive environment
- Sensing winding vibration with electrical sensors is frustrated by winding electromagnetic emission
- In the past, fitting sensors to windings is usually done on new Generators by the OEM

Large Overhangs Vibrate at 2 x Synchronous Frequency

A GEC Photo

Stator End Winding Function ?

1. A generator's electrical copper formers are secured with resin and wedges in their stator slots
2. Over time, the resin frets away resulting creating small gaps allowing increasing conductor movement
3. These gaps cause bending stresses in the windings and softens insulation rigidity as well as breaks it down
4. Bending makes copper work harden and then fractures
5. Absolute deflection is measured in microns by accelerometers
6. Accelerometers are mounted on the windings but are prone to electromagnetic effects and noisy signals
7. In hydrogen cooled generators extra safety precautions are essential due to its hazardous nature
8. The long term condition of the stator life is trended.
9. India has a growing experience in this specialist application developed by BHEL & Mechanalysis but further improvements are available now (see MIL-QPS)

Selected Stator End Winding Sites
29 Generators Monitors Supplied by MIL to BHEL

• KOTA TPS	210MW x3	-	SEW2 X3
• NTPC UNCHAHAR	210MW x2	-	SEW2 X 2
• NTPC VINDHYACHAL	210MW x2	-	SEW2 X 2
• NTPC FARIDABAD	210MW x3	-	SEW3 X 3
• NTPC KAYAMKULAM	210MW x3	-	SEW2 X 3
• NTPC SIMHADRI	500MW x2	-	SEW3 X 2
• NTPC TALCHER	500MW x4	-	SEW3 X 4
• DVB PRAGATI TPS	21OMW x1	-	SEW3 X 1
• DVB PRAGAT GT	110MW X2	-	SEW3 X2

Additional SEW Systems, of various versions, have supplied by BHEL Haridwar to different specifications from that designed by IRD/MIL. Prices have come down and latter systems are simpler but may not be better?

Development of SEW in India

- Early large generators (>500MW) had water cooled jackets at the end windings
- Trending vibration levels monitored the condition of the end windings and cooling system for fatigue
- Circa 1988 Westinghouse published a paper on using mirror based fibre optic sensing for SEW
- The UK Power Industry has used SEW systems for many years, it generally confirms winding tightness
- SEW vibration monitoring is a Structural and not a rotating machinery application; absolute displacement in microns is the basic measurement
- Around 1994 BHEL decided that the Westinghouse design was too expensive and a technology perhaps not available to India at the time

Development of SEW in India cont

- 1995 BHEL decided to use charge type accelerometers for absolute vibration in displacement. This posed technical challenges.
- Special micro-phonic cable required to connect inside the generator
- An order was placed on IRD Mechanalysis UK for a trial system that specified vibration and process parameters with short and long term trending in the same display unit
- IRD designed a double integration signal conditioning card that was made by IRD India for the then state of the art microprocessor VDU Monitor the model IRD5915 named SEW1
- Fifteen model IRD5915 systems were commissioned but then IRD found component suppliers had ceased production
- As a result the model IRD5915 was made obsolete in 2001 and replaced with IRD6600, an API670 DSP system, named SEW2
- The IRD6600 did not double integrate for displacement so the charge amplifier was customised for this purpose
- An independent software system for long term trending was supplied with model 6600 but was poorly maintained by the end users. Housekeeping was ignored.

Development of SEW in India cont

- MIL considered the BHEL specification was over designed being based on API670 architecture
- In 2000 MIL proposed a lower cost system to BHEL using a networked surveillance scanning but then its Joint Venture ended and MIL became independent
- In 2005 MIL suggested a lower cost system (MIL8700) SEW3 for higher reliability and obsolescence proof. This was not accepted as it was non-microprocessor
- In November 2007 MIL and QPS of Canada designed the Next Generation SEW based on fibre optics using FBG technology with its MIL8800 termed SEW4
- SEW4 was installed at TATA Bhira on TG3&4 in Feb08.
- MIL will offer its MIL8800 programmable monitor for a rate contract in April08 for accelerometer based systems (called SEW3) required by BHEL Haridwar

Evolving Technology & Cost Cutting

1.SEW1
IRD5915

Charge Amplifier

OBSOLETE 2001

DCS

2. SEW2
Entek6600

OBSOLETE 2004

DCS

3. SEW3
MIL8700

WOULD ENDURE

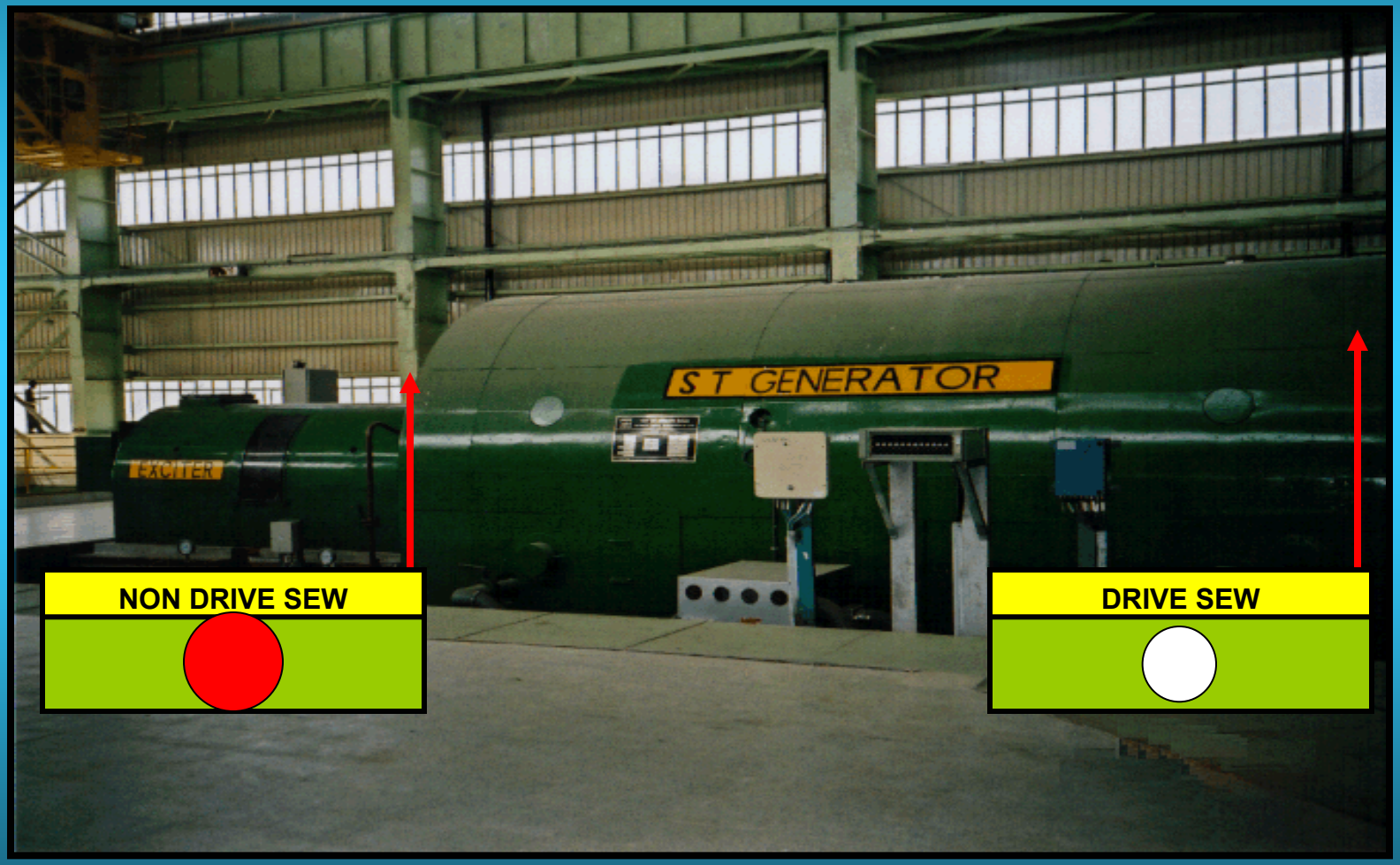
DCS

SEW1-3: Technical Details

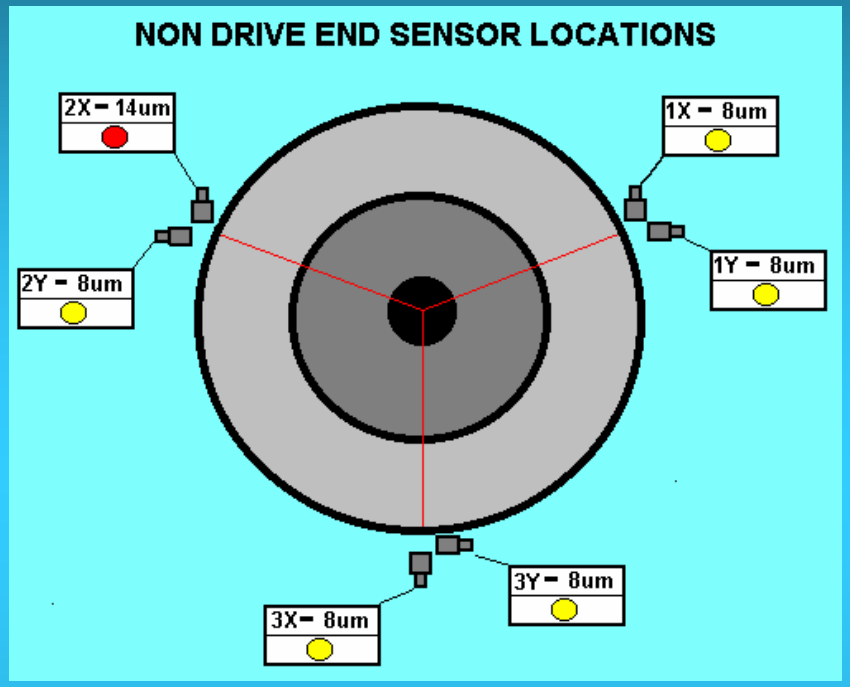
MAIN COMPONENTS OF AN SEW SYSTEM

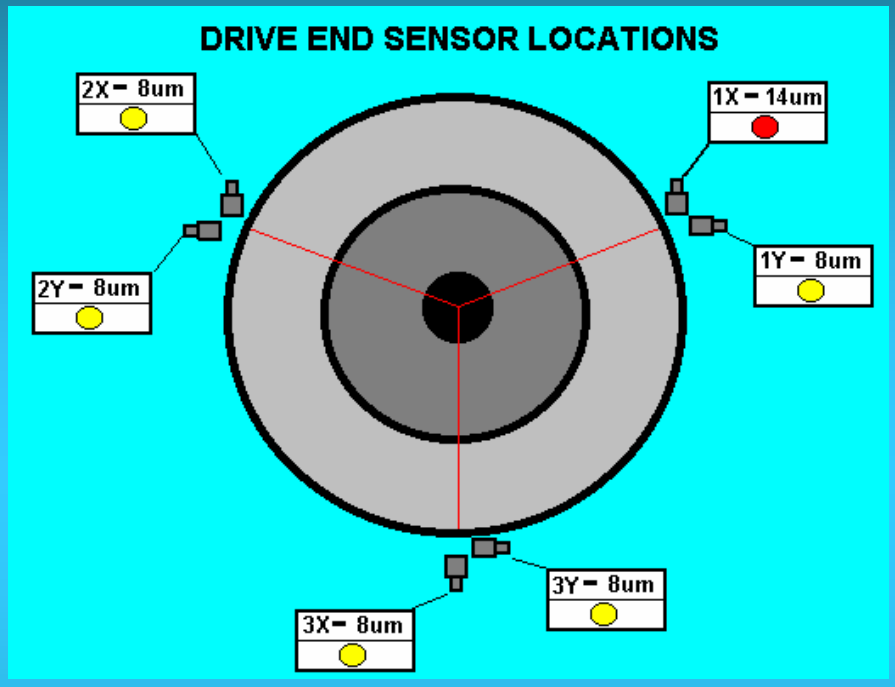
- ACCELEROMETERS
- CHARGE AMPLIER – filtering
- IS BARIERS
- VIBRATION MONITOR MODULE
- Cabinet & Cables
- Optional:
- PERSONAL COMPUTER
- SOFTWARE

SEW in Service
A Typical Hydrogen Cooled Generator



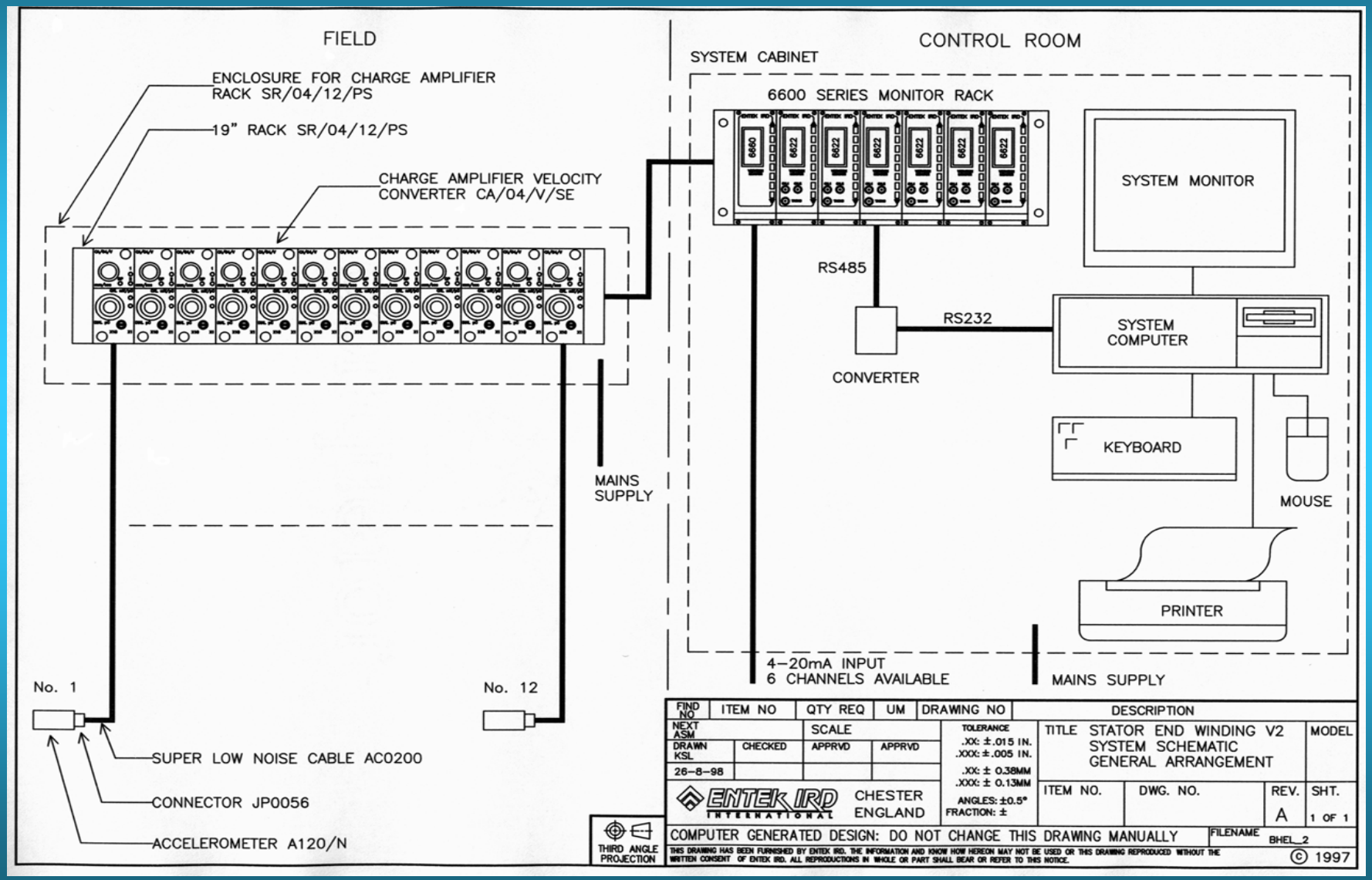
Stator End Winding Accelerometer Matrix Accelerometer Locations





- Sensors need to measure radial and tangential vibrations and are position at each end of the generator
- Locations 120 degrees apart are considered economic
- Attaching accelerometers to the winding is invasive and can only be done by the OEM during the winding manufacturing process

SYSTEM SCHEMATIC



Sensors Terminating at Generator

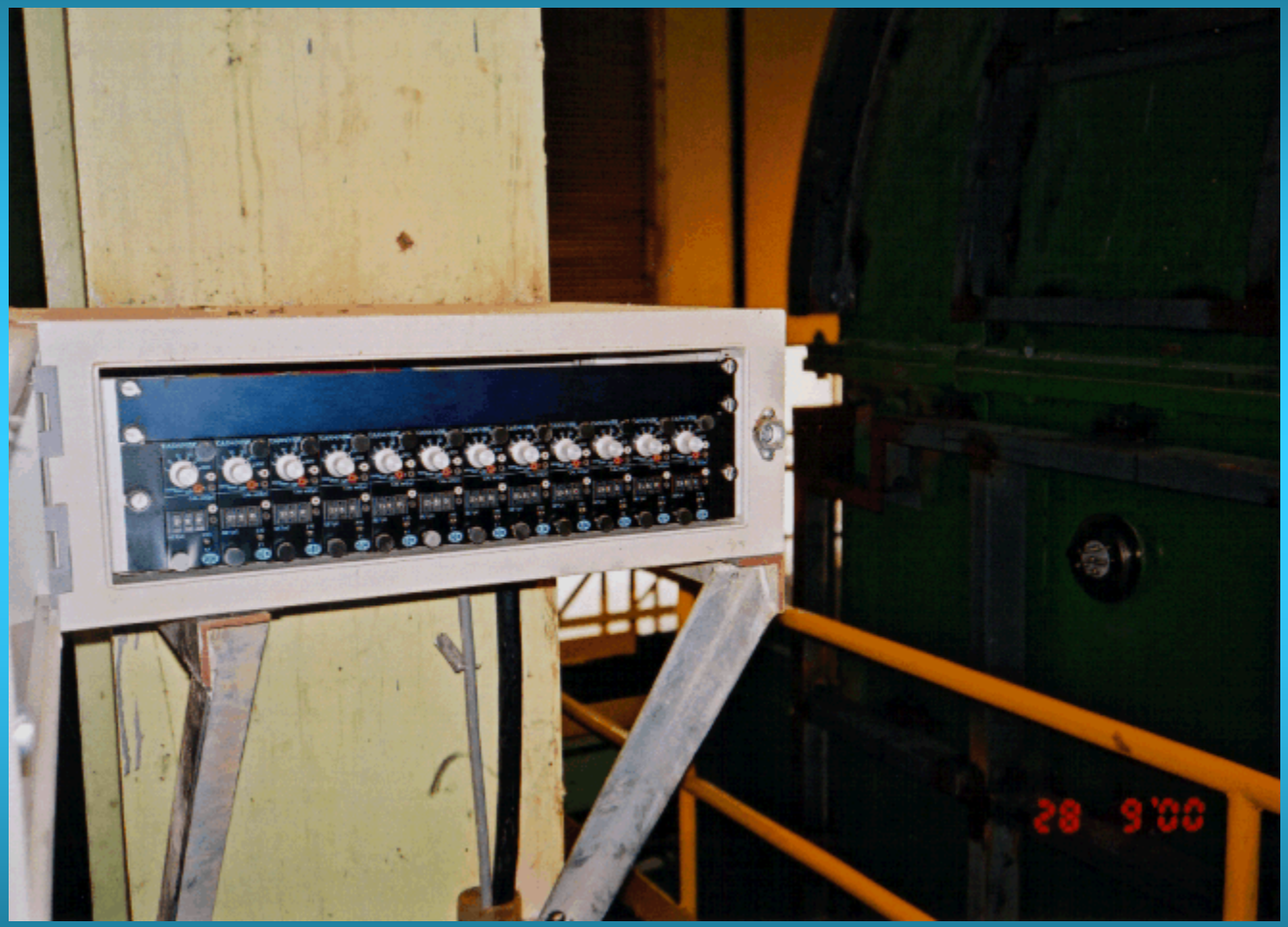
The Accelerometers terminate at the BNC sockets ensuring sealing to contain the hydrogen. They connect to the Charge Amplifiers

The Charge Amp – 1st Stage of Integration - PN CA/04/V/SE

KEY CHARACTERISTICS

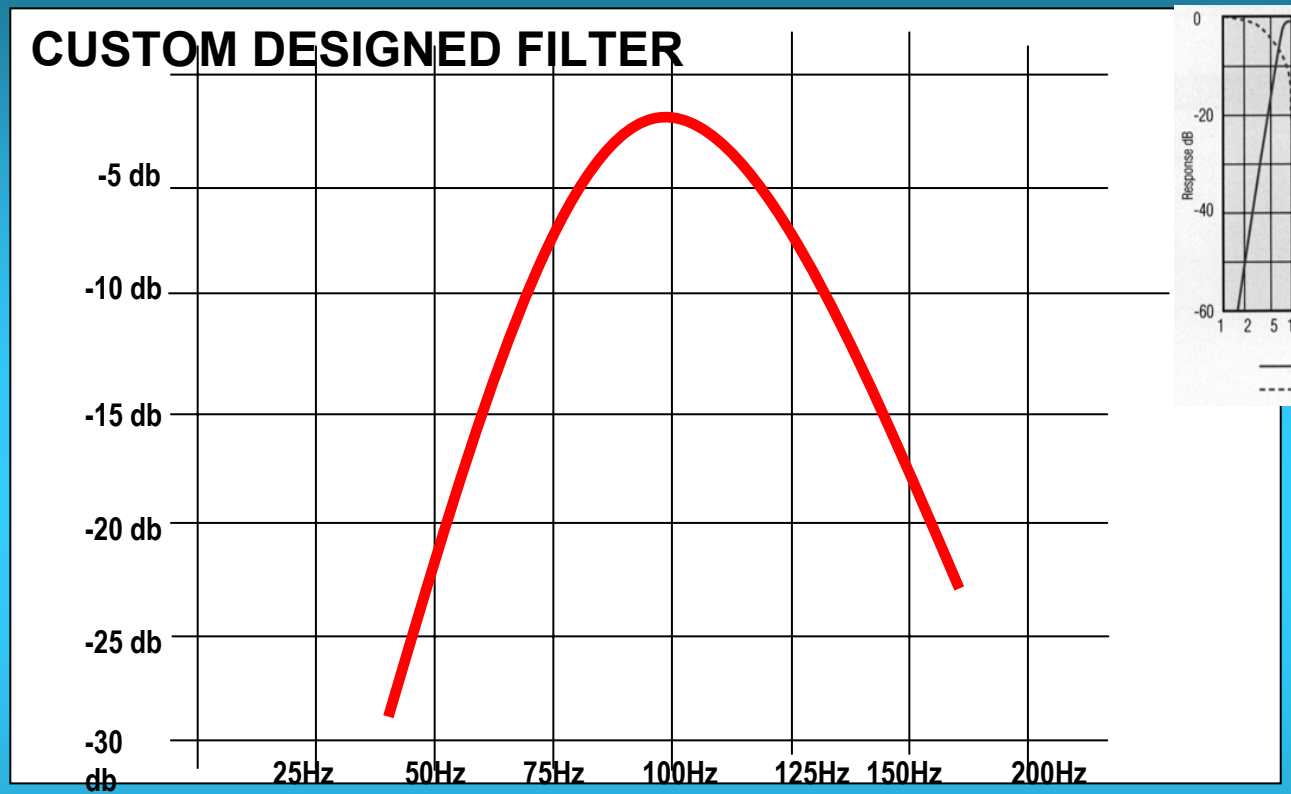
INPUT	single ended
MAX INPUT CHARGE, Nc	12
IMPUT CAPACITANCE LOADING	10nf=1% gain reduction
NORMALISING RANGE pC/g	1/100
NOISE LEVEL @ 1pC/g	0.05mm/sec + 0.05/sec/1nf input capacitance
OUTPUTS 1 ACCN Mv/G	SINGLE ENDED 100+-2% @ 500hZ, 3DB BANDWIDTH 3hZ/100khZ
OUTPUT 2 VEL., SWITCH, SELECTABLE 10db mm/sec/V	1, 3.16, 10, 31.6, 100, 316 +- 3% @ 500Hz bandwidth 20Hz/10KHz
PEAK O/P VOLTS @ Vs=+-15V	+- 12V, O/P's 1&2
PEAK O/P CURRENT O/P 1&2, Ma	+- 10
OUTPUT IMPEDANCE, O/P 1&2	<10 ohms + 47uF
SUPPLY VOLTAGE Vs, V	+- 10/15
SUPPLY CURRENT, Ma	+- 15

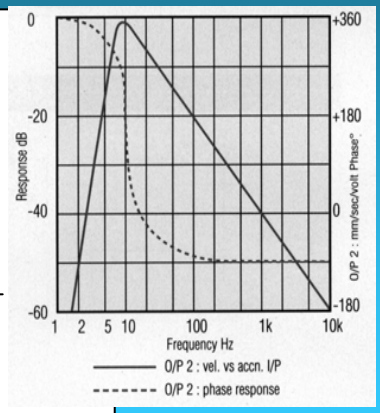
Charge Amplifier in Site Mounted Cabinet



The Charge Amplifiers is for 12 Channels in an IP65 Cabinet

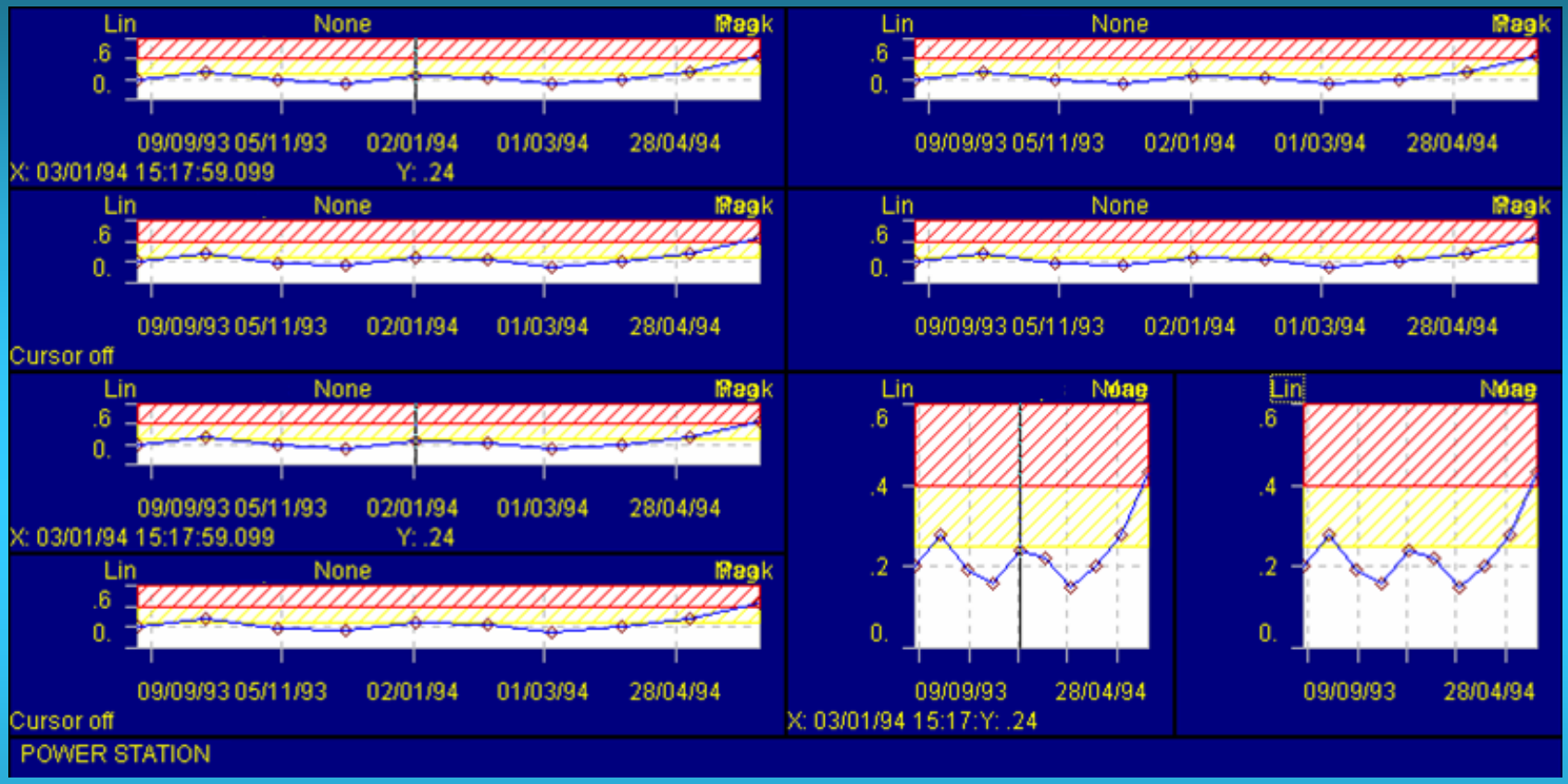
The Charge Amplifier Filter Characteristics





- SEW is a structural monitoring system. The Windings are excited by 50Hz but to avoid a high level of signal noise the first harmonic at 100Hz is measured
- A filter from 80 to 120 Hz gives a central frequency of 100Hz allowing for slight frequency variations to give the optimal value

SEW Data to DCS: Trending Options



- **Most Distributed Control Systems (DCS) archive data monthly and seldom is this easily retrieved. SEW trending is a long term requirement.**
- **It is best if there is an independent trending system or chartless recorder for say at least 12 months of trend data**

Trends in BHEL SEW Specifications

- We have noted the following variations in specifications issued:
- System to measure Line Frequency 1LF, 2LF and Sigma – while this is simple by programmable filtering only 2LF is the prime signal
- Some research indicates slot faults or vibration at 1LF but needs to be separated from electrical noise, not practical with accelerometers
- System to measure displacement and velocity when selected – as a structural monitor, absolute displacement is more meaningful and an international norm
- IS barriers fitted between Monitor and Charge Amplifier – depends on charge amps
- Latest tender indicates Velocity only – this is a less complex option but not suitable for a structural measurement

Mechanalysis Condition Management Solutions for NextGen SEW

1. Measurements should be absolute displacement
2. Fibre Optic systems are now viable and cost effective – back to the future! (re Westinghouse)
3. The accelerometer design is invasive and can only be done on new or fully reconditioned generators
4. Experience has shown the accelerometer system to be prone to noise. International Cos. use Fibre Optics.
5. Fibre optics are hazardous proof, no incendive signal is used in the process & is self calibrating and long life
6. Installation takes hours rather than weeks for accels
7. Fibre Optics make R&M projects viable
8. The MIL-QPS VibroFibre™ system measures absolute displacement vibration directly.
9. MIL's SEW4 system is installed and operational at TATA Bhira Hydro station on two generators

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condition management solutions

Engineering the Environment

Taking you Further – The Next Generation

Mechanalysis-On-Line and QPS Photronics

Stator End Winding Vibration Monitoring – SEW4

TATA Bhira Hydro – Commissioned 1929

- This Bhira site has 6 x 25MW Pelton type Generators installed
- The early English Electric units have been upgraded

TG3 & TG4 Stator End Winding

The Plant had experienced a winding failure and consequential damage due to sudden high vibrations

TG3 & TG4 Stator End Winding

Corrective action taken was to use a putty resin to secure the windings as a temporary measure

MIL Responded to a Tender for a Fibre Optic Stator End Winding System

- The TATA specification called for a fibre optic vibration system to avoid electromagnetic radiation problems associated with accelerometer systems.
- MIL had supplied 28 SEW systems to BHEL in the past using the older accelerometer technology
- The original systems involved accelerometers that were fitted on special brackets that have to be built into the stator end windings only when newly manufactured.
- The Fibre Optic approach solved many past problems but principally can be fitted on a generator at any time as it is non invasive and takes little outage time. Say 1 day.

Mechanalysis Partners with QPS Photronics of Canada

- In 2006 Peter Kung patented a Fibre Bragg Grating termed VibroFibre™ a fibre optic FBG sensor to measure vibration
- The QPS data logging system is integrated with MIL8800 on-line protection monitor (API670) to provide traditional plant communications
- TATA Projects of Mumbai were convinced that the MIL-QPS solution was superior to two other overseas bidders and was awarded the contract in Nov 2007. System commissioning was completed early March 2008 on two TGs

After acceptance trials the system will be expanded to a further 4 TGs

MIL - QPS SEW Generic Architecture

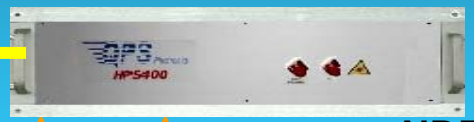
Protection Monitor API670

4-20mA
RS485- MODBUS

Relays

QPS Data Logger

SERVER

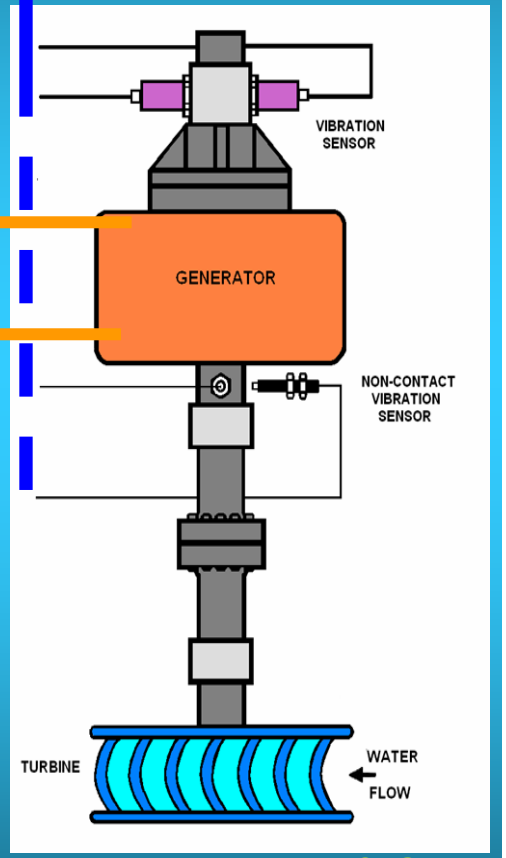


Bearing Vibration Signals

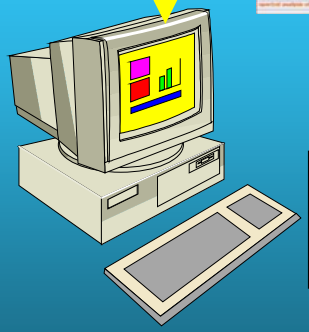
NDE

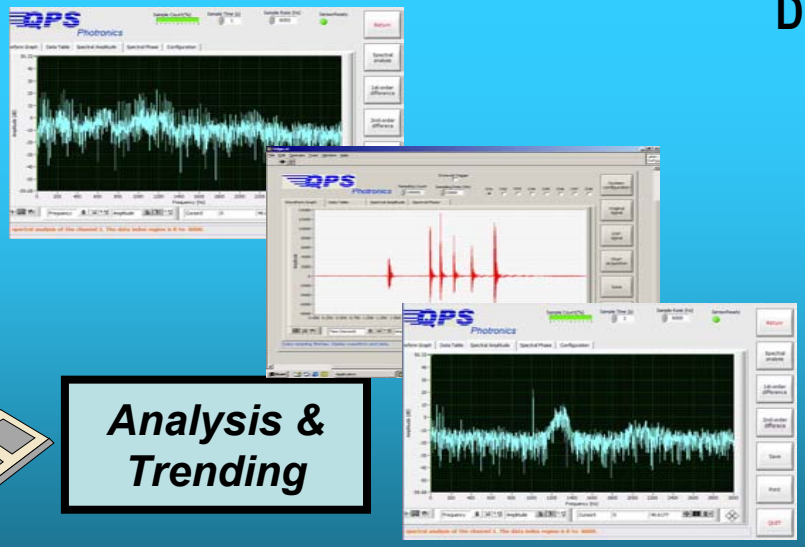
VibroFibre Signals

DE



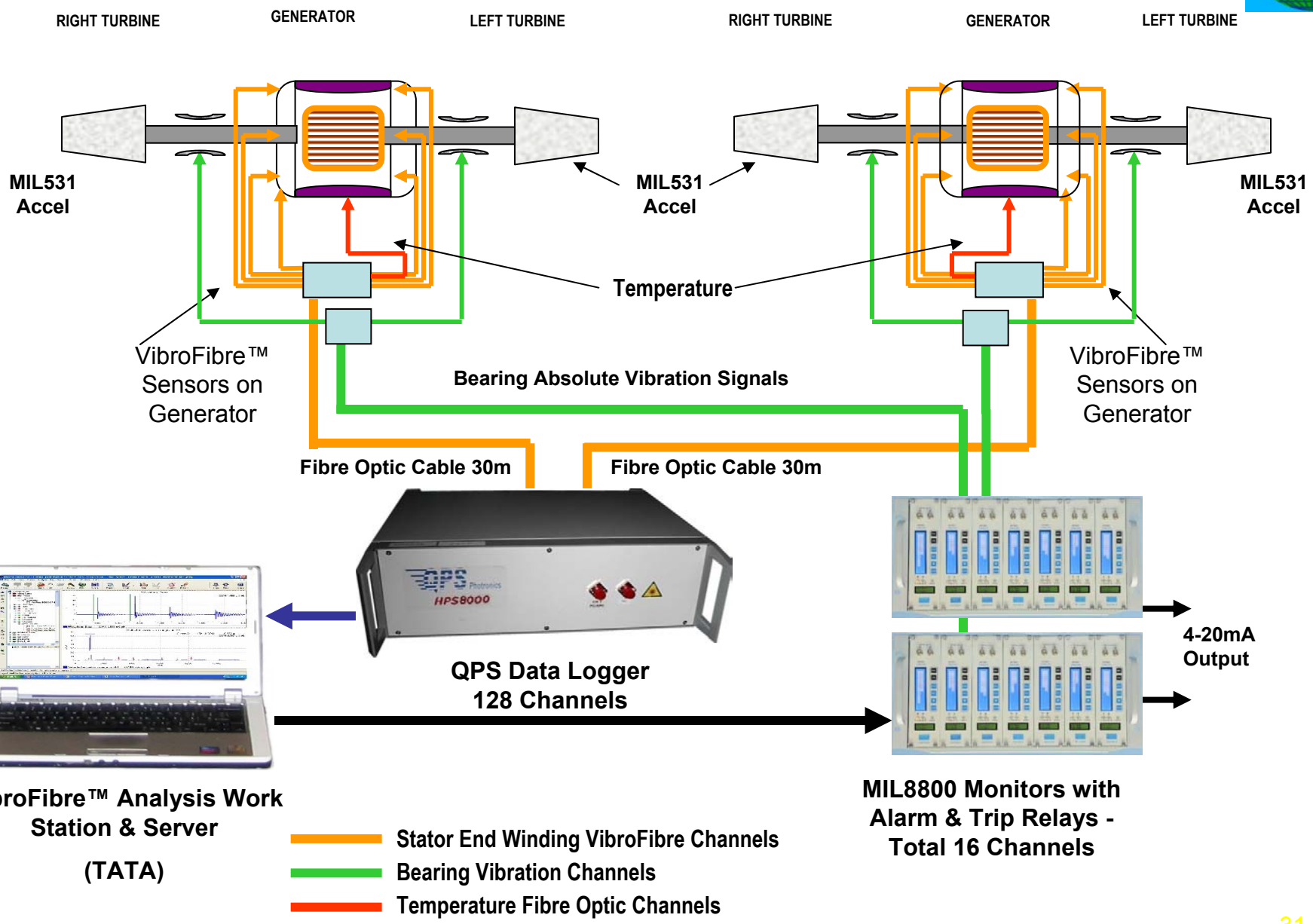
Bearing Vibration & SEW Integrated Monitoring





Analysis & Trending

TATA Bhira Hydro – VMS & End Winder Architecture for 2 Turbines



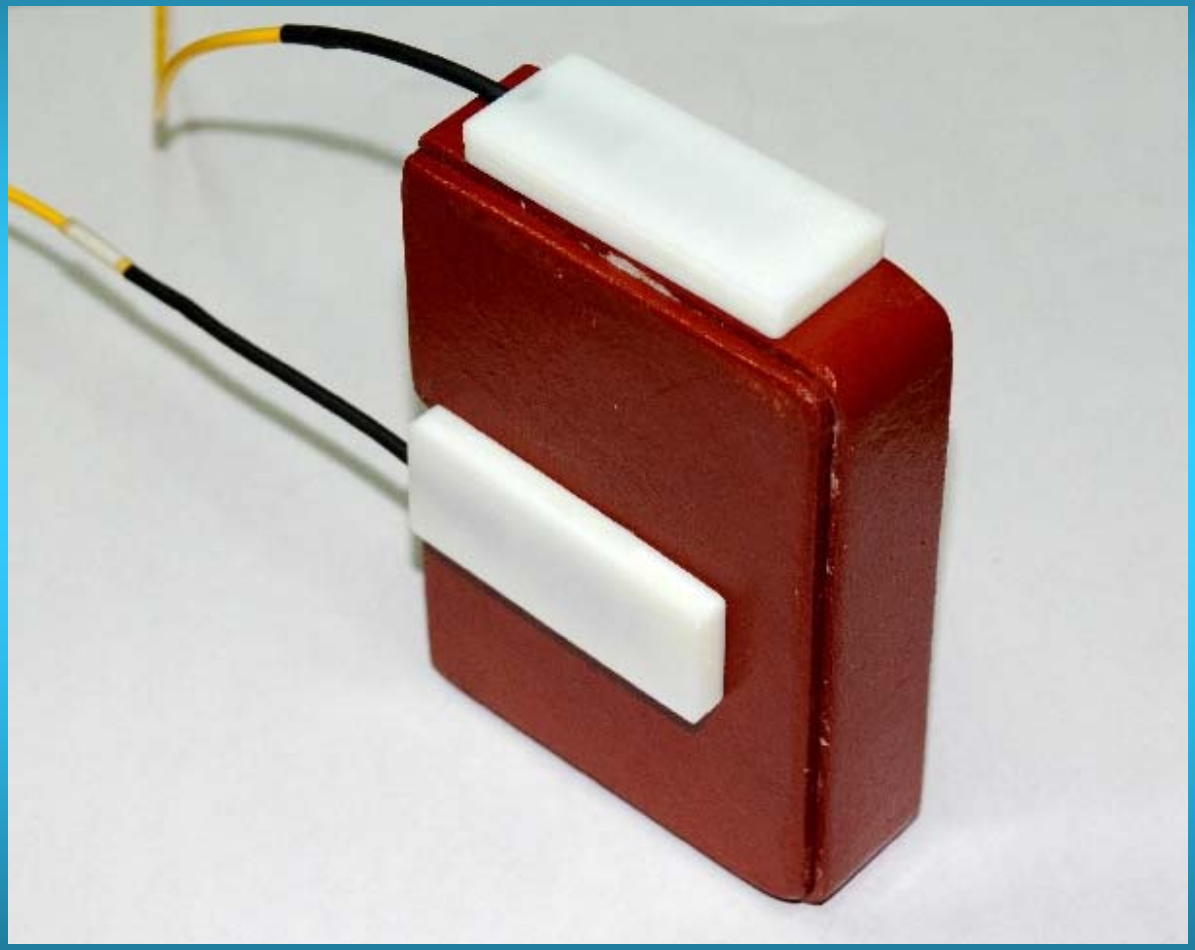
Sensor Calibration at Mechanalysis Mumbai Traceable to National Standards

Pre-commissioning sensor tests at MIL Works

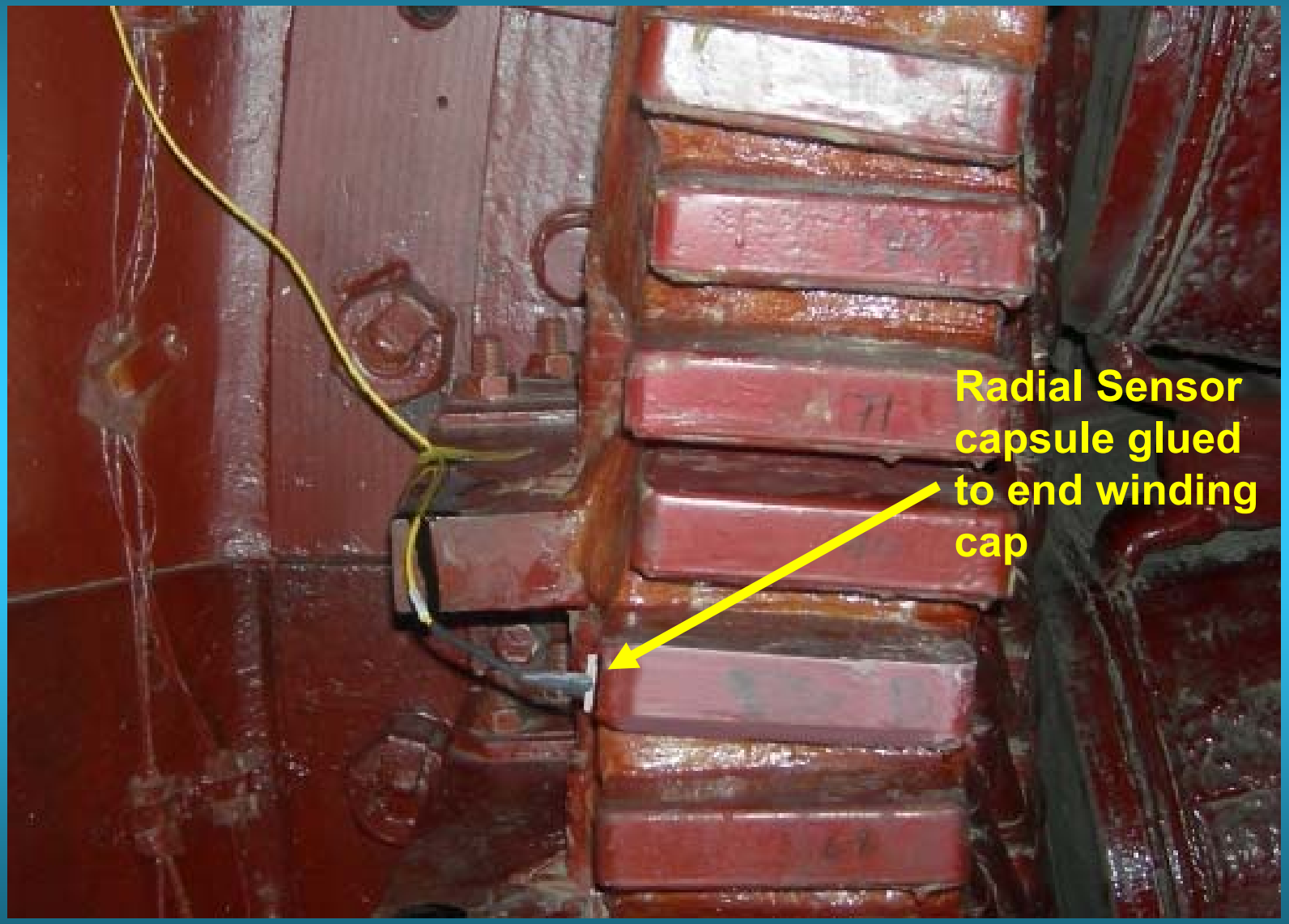
Multi-Stack Sensor Calibration for Consistency and speed of test

Sensor Orientation on Stator End Caps

- Sensors mounted on winding's end caps
- Positioned at Radial and Tangential positions
- 3 radial sensors located at 120° apart
- 1 sensor at tangential position



VibroFibre™ Installed on Generator



FBG SEW in Operation

An Indian and World First

TG3

TG4

- MIL8800 On-Line Protection Monitors
- 4-20mA output, warning and alarm relays, RS485/MODBUS
- QPS – Data Logger & Laser Generator and Signal Processing

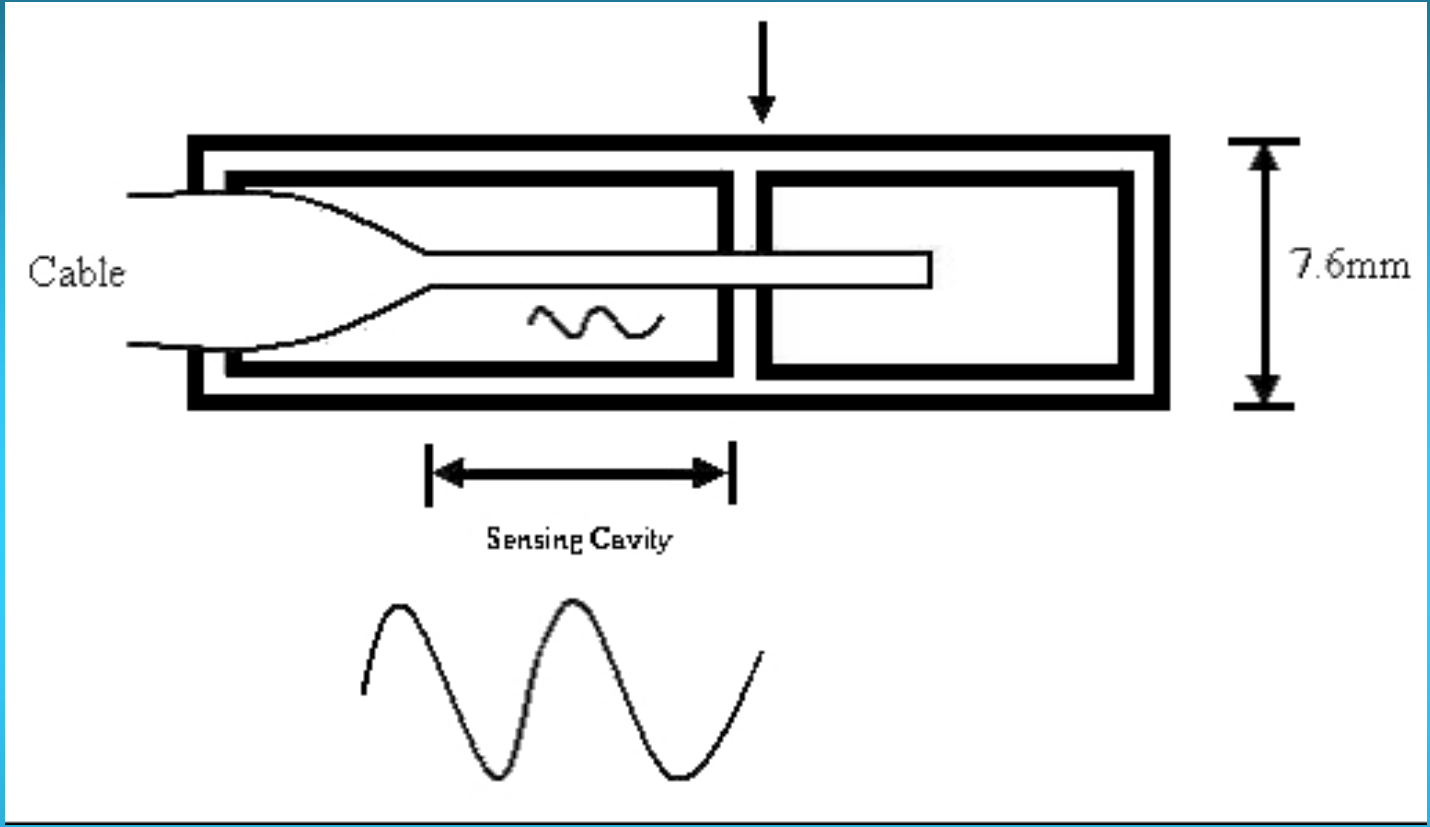
VibroFibre™ System Commissioning

- The rear terminals of the MIL8800 VMS
- The fibre optic data logger output sockets
- A computer is used to configure sensor sensitivity across all channels
- Each signal from the VibroFibre™ sensor is verified and time waveform signal checked
- Levels are recorded against various machine operating conditions

How Does VibroFibre™ Work?

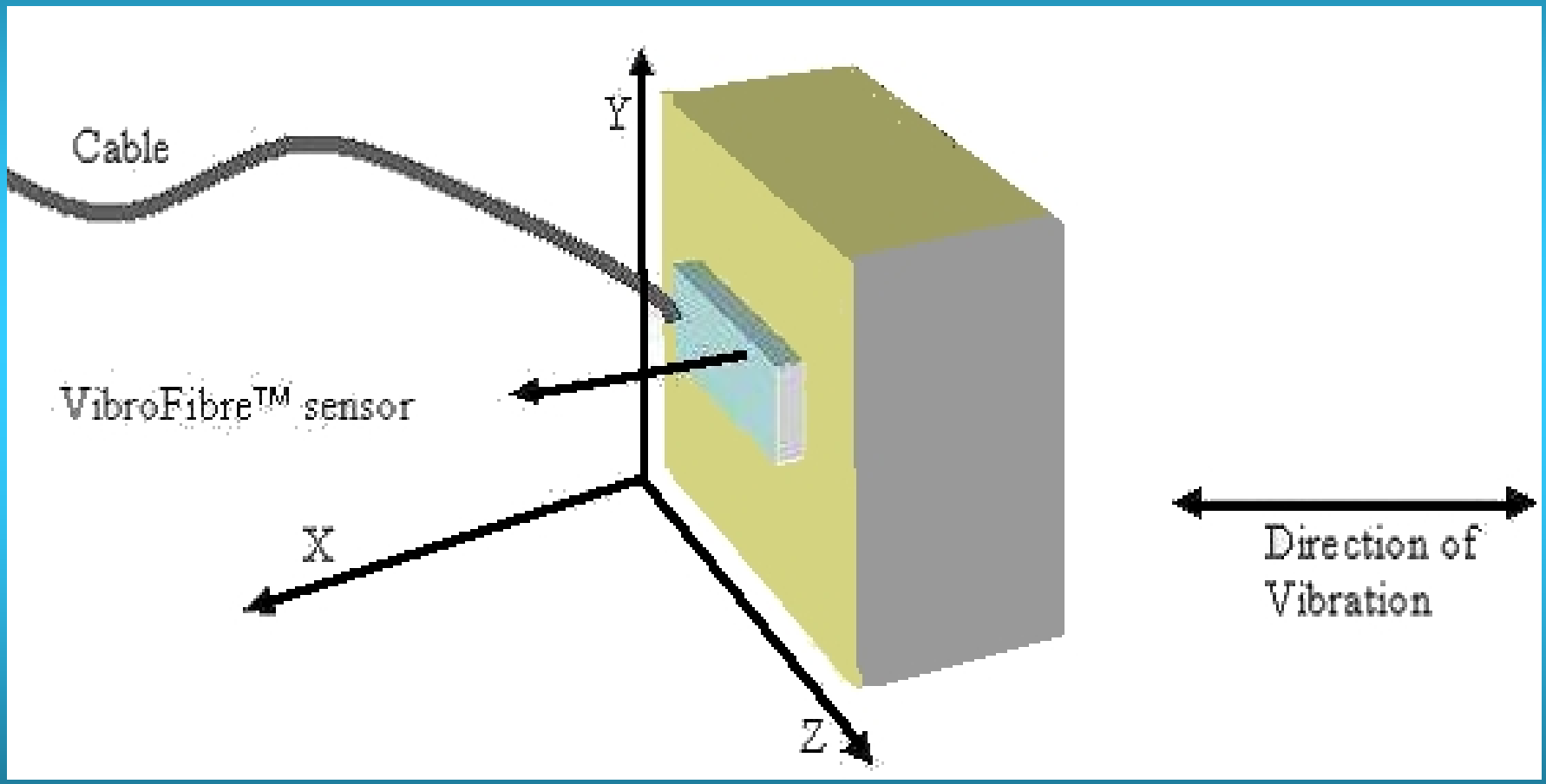
- VibroFibre™ Technology is based on the detection of distortion of a fibre optics cavity.
- When a vibration signal is present and is properly coupled. It causes the optical path to change.
- For high frequency surface waves, the package material must not absorb the signal so is tightly coupled against the substrate with silicon gel.
- For the monitoring of turbine generator, the signals are low in frequency.
- Sensors respond to such low frequencies, typical 100Hz with the help of a mechanical amplifier.

Fully Encapsulated VibroFibre™ Sensor



- By applying two identical caps, one top, one bottom, we can create a dustproof, oil proof environment for the sensor head.
- The material used in such encapsulation is a special high temperature ABS Plastic. It will stand up to and operating temperature of 100°C.

Measures in Any Direction Selected



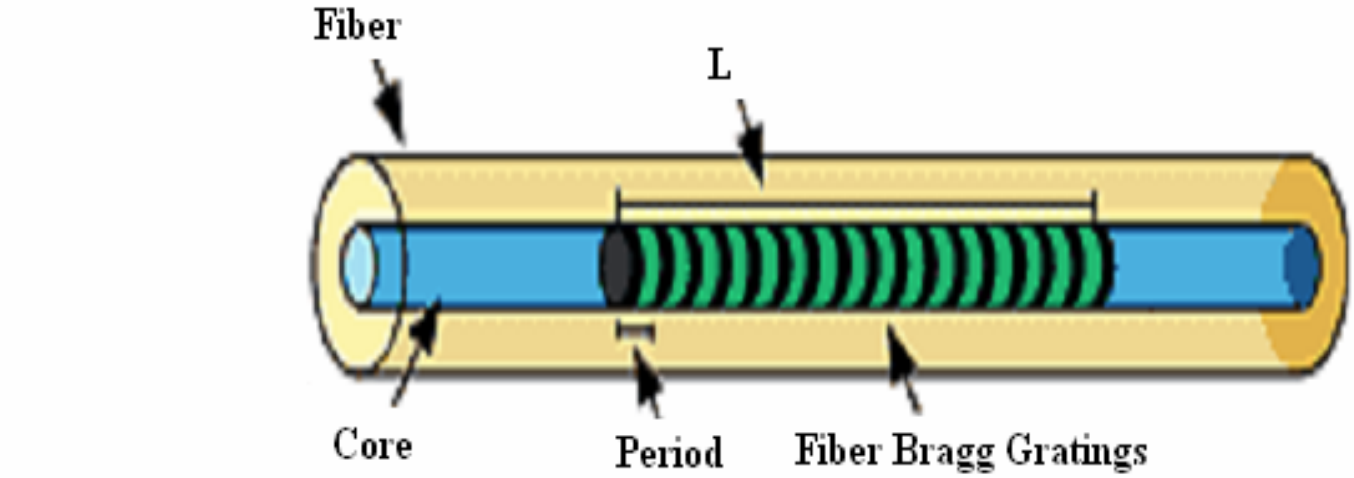
Why is VibroFibre™ Unique ?

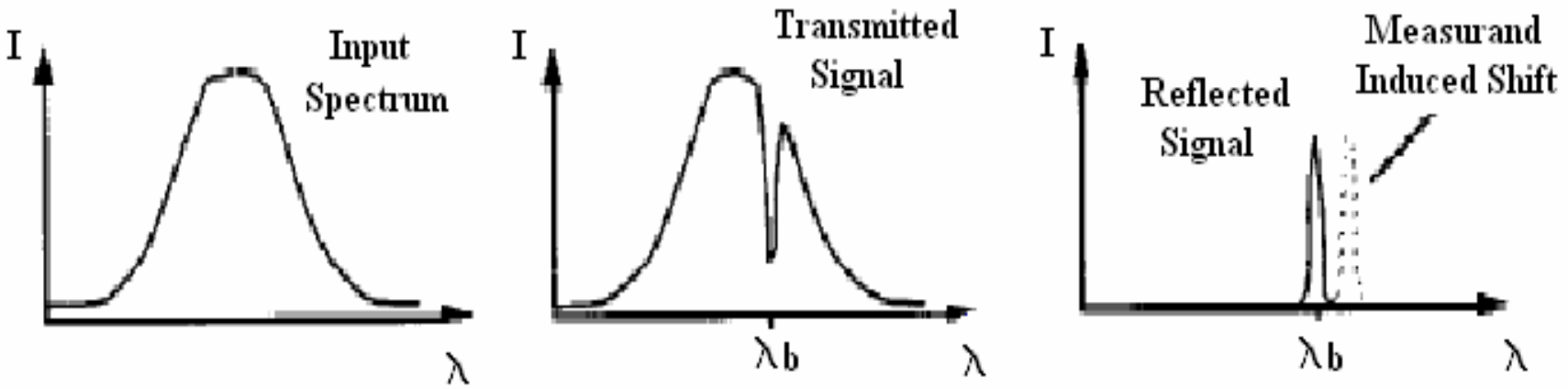
- The Westinghouse FOVM fiber optic vibration monitor was patented in 1996
- It employs a light beam directed on a canterlever mounted grid (mirror) sensor
- The light beam is proportional to sensor's deflection and hence is an 'Optical-Mechanical device'
- The VibroFibre™ sensor is solid state in that it employs FBG on a single strand of specially treated optical fibre

What is FBG ?

- Applies ‘Single-Mode’ Fibre Bragg Grating (FBG) technology
- Gratings are tiny mirrors etched into the fibre that reflect laser light
- A pair of etched mirrors makes a cavity sensitive to vibration in the fibre
- Interference fringes are related to the amplitude and frequency of the vibration signal
- This provide a technology platform that can be used in many applications

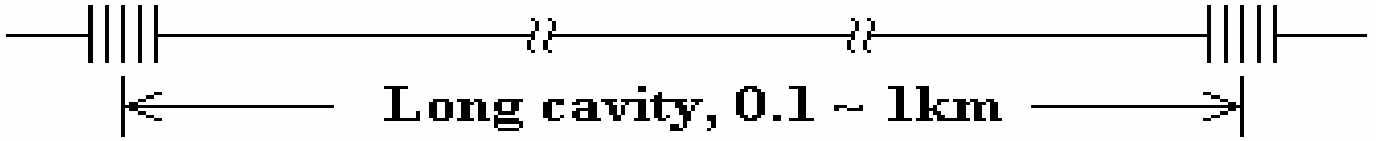
FBG Technology



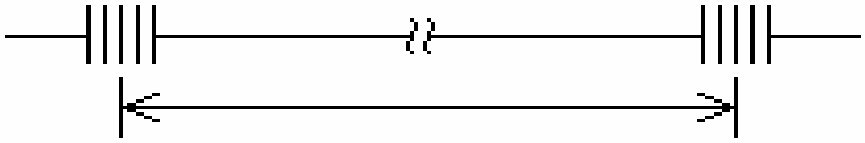


VibroFibre™ Sensor Ranges

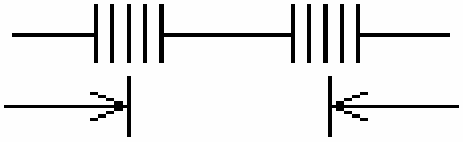
EDM FBG



Sensor head for Perimeter Security such as piplines, wind turbine blades



Medium length cavity, 0.1 ~ 10m
Sensor head for impact studies



Small cavity, 2 ~ 5mm
Sensor head for dynamic strain, presure, high speed vibration as well as AE

Features of VibroFibre™

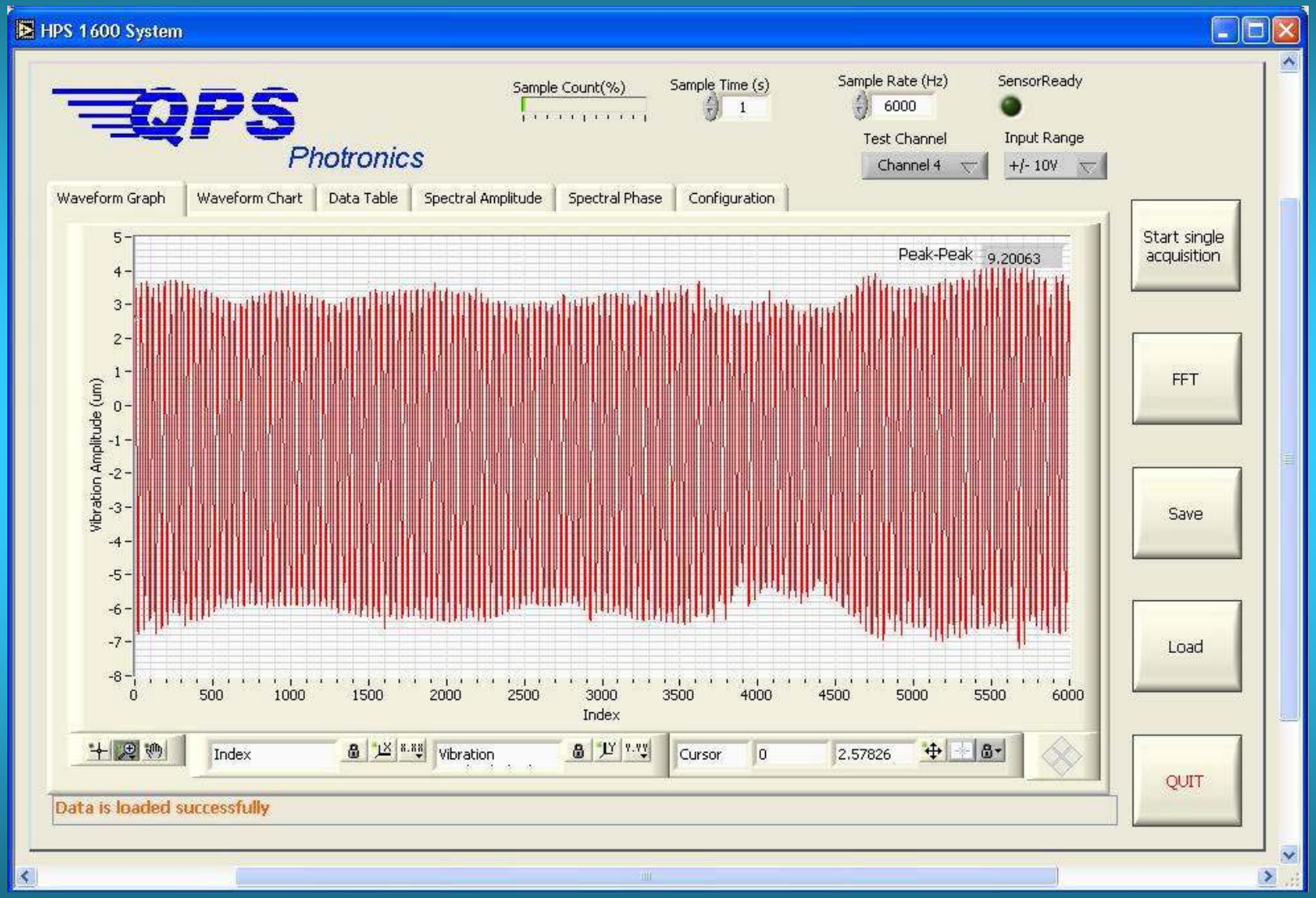
- Sensing mechanism in standard glass fiber
- Low loss sensor head made with twin FBGs
- Glass material is inert , passive, draws no power, hence intrinsically safe
- Sensors form a Star Network up to 128
- Mature technology with volume capacity
- Small size light weight , simple packaging
- Broad band frequency response of up to 3MHz
- Sensitivity can be optimized by cavity length

VibroFibre™ Sensor

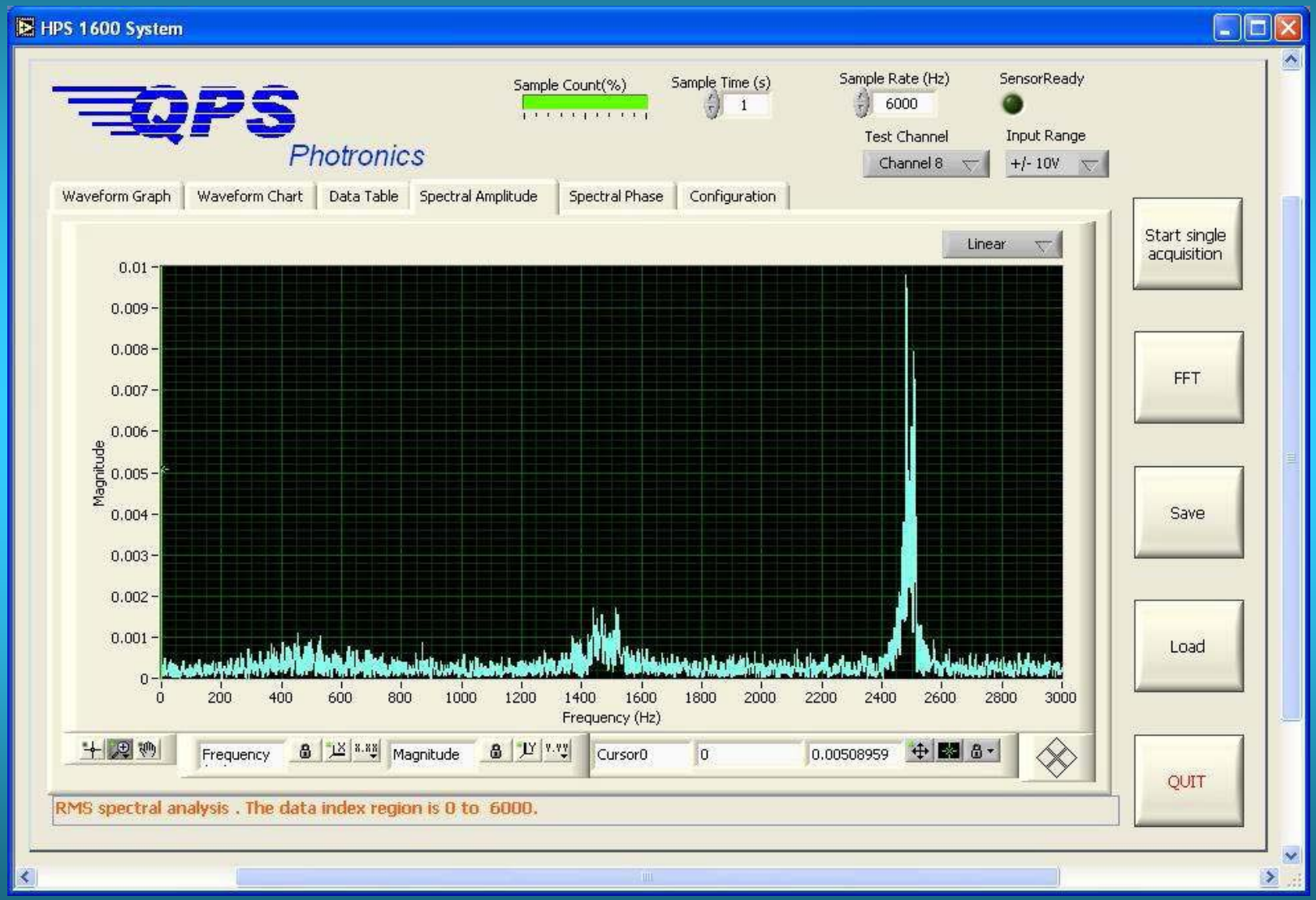
Interrogation Method for VibroFibre™

- Based on mature DFB laser Technology originated from the telecom industry
- Ideal for parallel measurements at high speed
- Optical vibration signal converted to analog voltage output
- Plugs into existing Data acquisition systems for complex signal analysis, modal analysis and pattern recognition.
- No new training or software development required
- Each laser can easily support 8 channels, with programmable signal conditioning

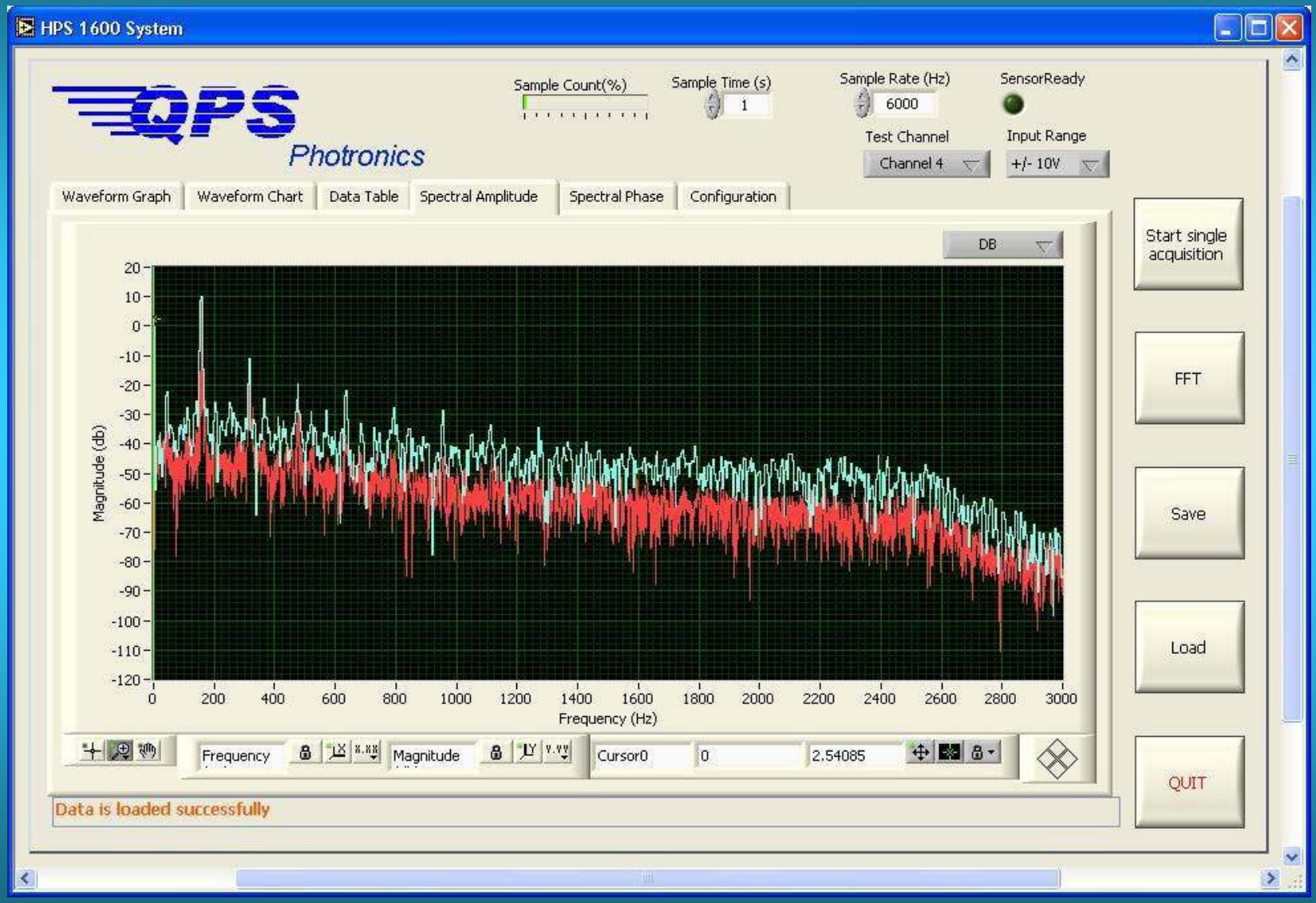
Vibration Signal Acquisition



Signal FFT Analysis



Compare Load with FFT Spectrum



Operators Warning & Alarm Station

API670 Compliant from MIL – Designed and Made in India

- The MIL8800 is microprocessor based, programmable at key pad
- High and Low Pass Filters are adjustable
- Warning and Alarm relays for each channel
- Communications include isolated 4-20mA output, RS485/MODBUS
- SMPS power supply for each module, no common mode failure

What Others Power Companies Say:

Avoid Potential Forced Outages: GEC

- **Early and accurate detection of excessive vibration in generators is key to finding problems before they turn into costly forced outages.**
- **A proven way to detect vibrations is to continuously monitor specific locations within a generator—such as the end-windings, high-voltage terminal leads, core punching, excitation leads and transformers, and stator bar windings.**
- **Results can be trended with a recorded historical database, enabling similar units to be compared.**

Causes of End-Winding Vibrations: GEC

- **As generators age, the end-winding support structure begins to become more compliant.**
- **Increased compliance heightens the forced vibration, resulting in reduced resistance to the 120 Hz**
- **Vibratory forces naturally found in the stator end-turn region (100 Hz for 50-cycle machines).**

On-line stator vibration monitoring is no more only a protection device but also a maintenance optimisation tool: Power Gen UK & EDF France

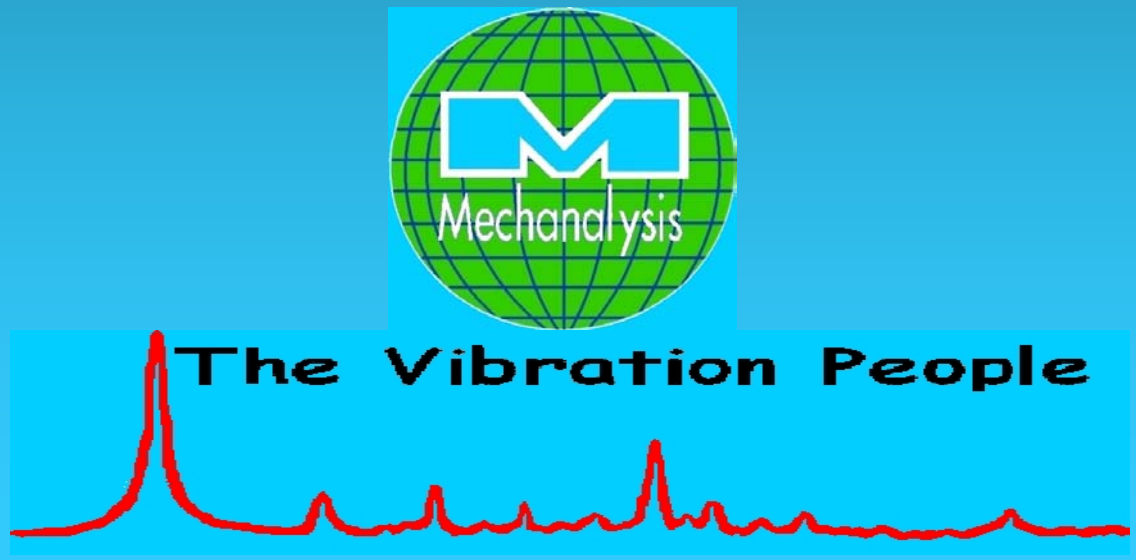
Mechanalysis-On-Line

- MIL has >30 years experience supplying machinery protection monitors in India
- MIL has built upon its experience to innovate and develop World Class Systems
- MIL continues to support all products sold where 3rd party suppliers still respond
- Mechanalysis is the Exclusive Distributor for QPS Photronics for South Asia
- Together we are taking VMS forward in the 21st Century to greater reliability and value

CONTENTS

The Mechanalysis Approach

- Getting you started
- Keeping you going
- Taking you further



Thank you for your attention

condition management solutions

Presentation by: Peter W. Hills (MIL) and Peter Kung (QPS)

Any errors and omissions are regretted, this is not intentional

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