Protection and Condition Monitoring of the LM5000 Gas Turbine

By Chris James • SKF Reliability Systems

Overview

The LM5000 Gas Turbine

The LM5000 Gas Turbine is derived from General Electric's CF-6 family of aircraft engines, which has seen service on large aircraft such as the Boeing 747 and C-5 Galaxy. In industrial applications it is adapted mainly for power generation.

The LM5000 is a twin spool Gas turbine Generator (GG) with a high pressure (HP) spool, a low pressure (LP) spool, and a free power turbine (PT). The power turbine is directly coupled to a generator for 3600 RPM phase synchronization, and output between 30 MW–50 MW.

The LM5000 was first introduced in the early 1980's. In the following decade, demands for power increases, together with the need to meet new NOx emissions, stretched the design to its limit, and by the mid-1990's the LM5000 was being phased out in favor of the LM6000 Gas Turbine.

A modest fleet of LM5000 remain in service today, mostly in North America.

LM5000 Monitoring

The basic monitoring requirements for the LM5000 are defined by GE in the Installation Design Manual (IDM).

The LM5000 is commonly equipped with accelerometer sensors and a basic suite of analog vibration monitor instruments.

However, as electrical products age, monitoring system reliability and obsolescence becomes an issue, and enhancement of the monitoring system, to modern digital technology, becomes a technical and economic necessity.

Furthermore, the LM5000 has been known to exhibit high vibration, particularly on the cold section. In response to this, GE issued a service bulletin recommending upgrade to incorporate Broad Band vibration monitoring in a specific frequency range.

Figure 1. LM5000 derives from the CF-6 Aero Engine.

LM5000 Vibration Monitoring Upgrades

SKF DYMAC and Vibro-Meter's new generation of sensors and monitoring systems provide a complete solution for the LM5000, for increased monitoring reliability and capability:

- ***High Temperature Accelerometers – Four (4) per engine***

  The proven vibration sensor of choice for gas turbines, the latest CA-series piezo-electric accelerometers offer increased reliability and improved immunity to transference vibration from the gas stream and structure.

- ***Displacement Probes – Four (4) per generator***

  For journal bearing monitoring, the newest design CMSS-series "proximity" probes offer improved maintainability and reliability over earlier generations.

Application Note
CM3082

- ***Digital Monitoring System***

  The VM600 monitor system provides a compact and programmable solution. An single monitor card type, the MPC-4, is used for protection of the entire machine train, see Figure 2, and offers the flexibility required for adequate LM5000 cold-end vibration monitoring.

- ***Integrated Condition Monitoring***

  A single CMC-16 data acquisition interface, Figure 2, provides high performance monitoring, trending and analysis tools integrated in the same rack system for increased reliability.

This application note will discuss in detail the recommended installation for protection and condition monitoring of the LM5000, while remaining fully compliant to the needs of General Electric's Installation Design Manual.

Sensors – LM5000

Figure 3 illustrates the basic sensor suite for vibration monitoring of a 60 Hz LM5000 power generation train. Owing to variations in GE purchasing policy, the exact model and make of sensor installed by the OEM will have varied slightly over the years. With the LM5000, steam and water injection provide the means of emission control, rather than the 'lean burn' techniques which dictate use of dynamic pressure sensors in the combustion chamber.

SKF DYMAC and Vibro-Meter would recommend its latest generation sensors for an instrumentation upgrade project, and these are listed in Figure 21. The diagram in Figure 4

Figure 2. VM600 for LM5000 with MPC-4 and CMC-16.

illustrates the complete measurement component chain for a power generation application. Let us now consider each of these measurement chains in turn:

Engine Casing Vibration

The vibration of the Gas Turbine itself is measured with two piezo-electric accelerometers.

The high temperature requirement necessitates the use of an externally charge amplified accelerometer, the model CA303 from Vibro-Meter, Figure 5.

The unit has a linear frequency range from 5 Hz to 8 kHz. Made of high grade inconel stainless steel, the CA303 can operate within specification up to 455°C (850°F). An integral, mineral insulated, cable ensures good signal integrity for up to 2 meters (6 feet), to a locally mounted charge-amplifier, the IPC-704.

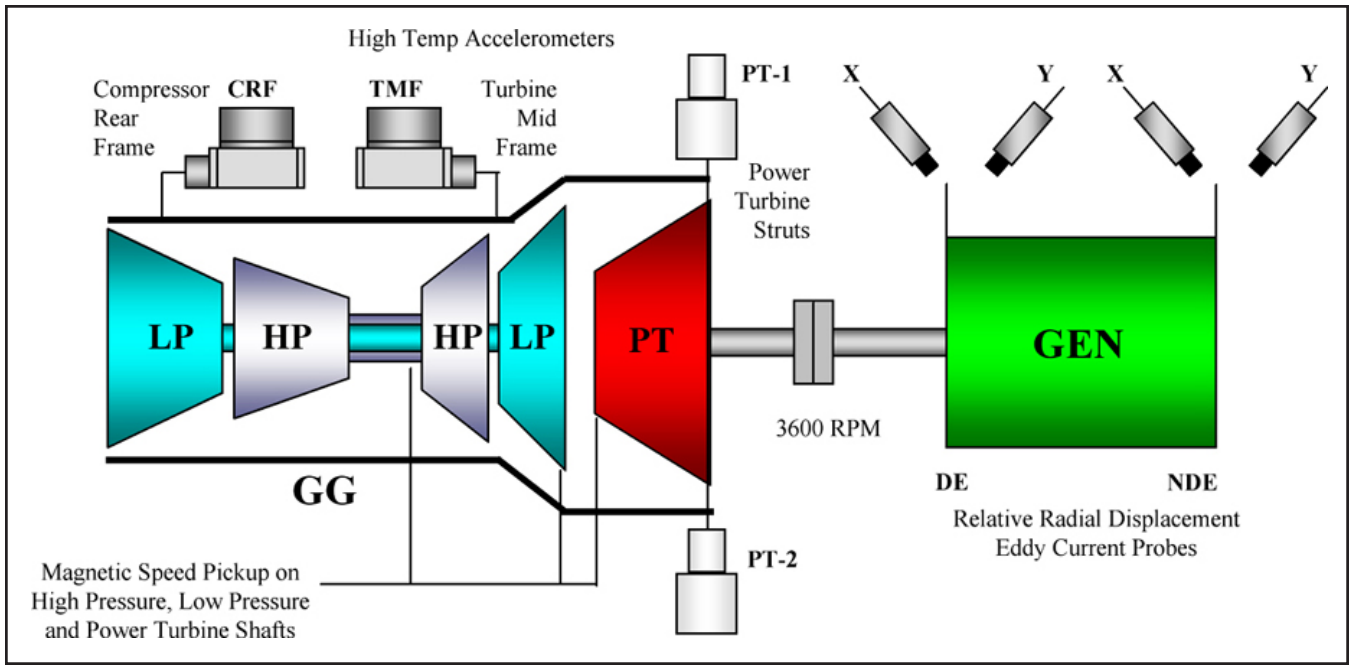

Figure 3. LM5000 Vibration Sensor Suite.

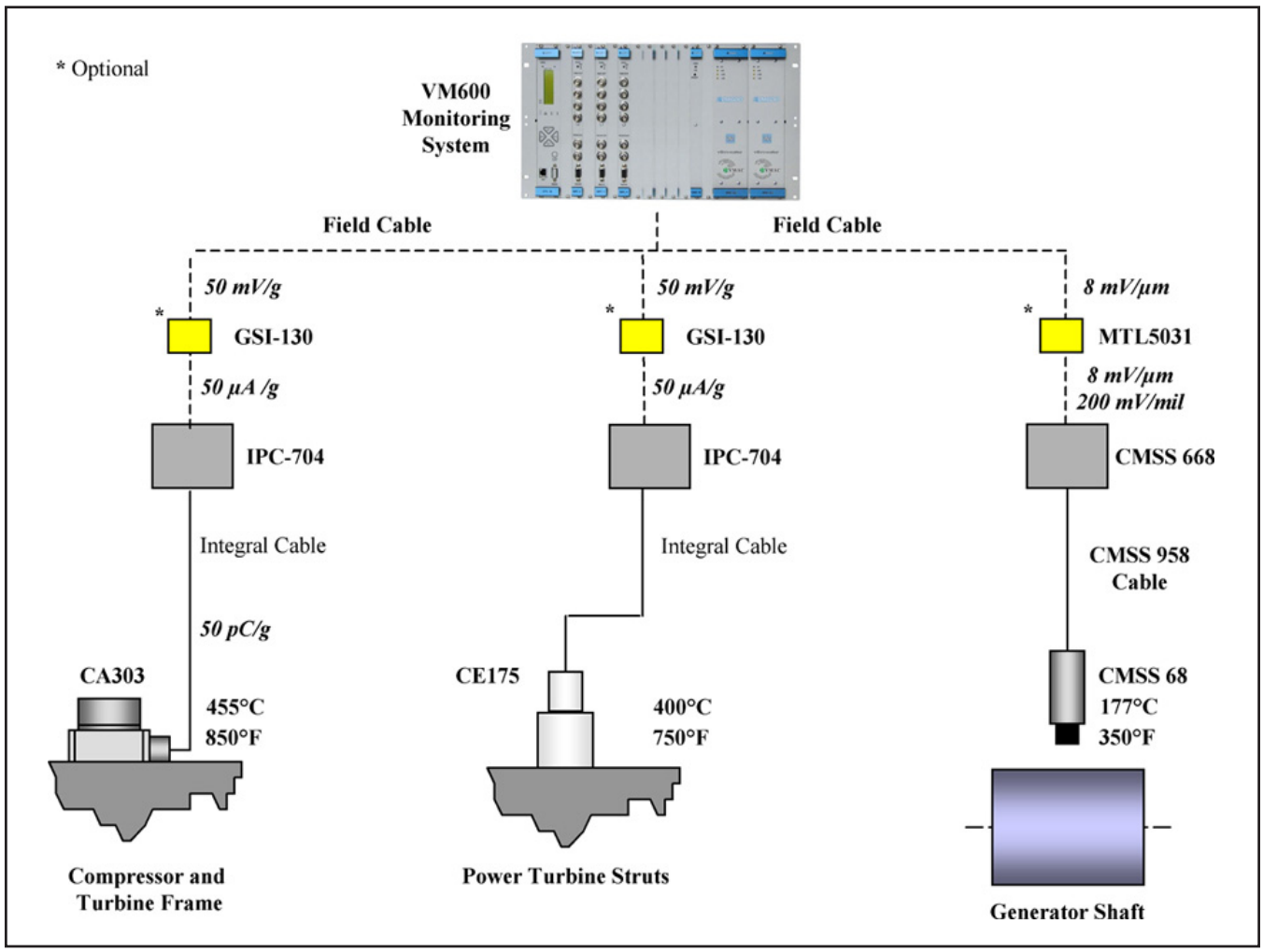

Figure 4. Sensor Measurement Chains.

The charge amplifier conditions the electrical charge output of the accelerometer to a current modulated signal of typically 50 µA/g.

In the application shown, galvanic separation is requested for electrical isolation, rather than prevention of explosive gas ignition. An optional model GSI-130 is used, with a Transfer Function of 1V/mA, providing a 50 mV/g output.

Power Turbine Strut Vibration

On any gas turbine, the rotating components are supported by bearings, which are in turn supported by "struts" mounted to the engine casing or frame, Figure 6 shows a "strut".

On an LM5000 package, the Power Turbine is monitored by two Vibro-Meter CA175 accelerometers. These transducers, specially built for GE, are mounted within support struts 3 and 7.

The CA175 can be supplied as part of any instrumentation upgrade project. However, owing to the location, mounting

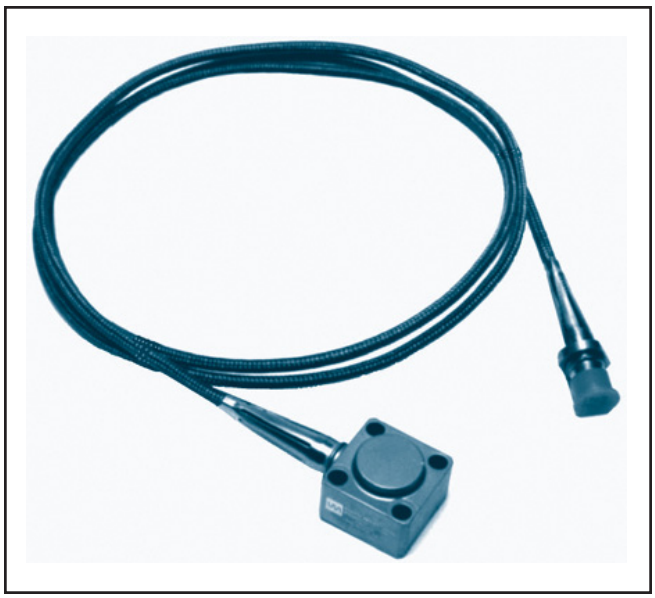

Figure 5. CA303 Accelerometer.

Figure 6. Strut Mounted.

and dismounting of these sensors is a tricky business, requiring special tools and expertise in working with the mechanical components of the power turbine. Hence they should be fitted in close co-operation with GE.

The CA175 covers a linear frequency response of 20 Hz to 350 Hz. The charge amplifier conditions the electrical charge output of the accelerometer to a current modulated signal of typically 50 µA/g. Again, an optional model GSI-130 is used, with a Transfer Function of 1V/mA, providing a 50 mV/g output.

Relative Shaft Vibration

The vibration of the driven component is usually measured by means of non-contacting sensors, known as "eddy current probes" or "proximity probes". These sensors provide a direct measurement of shaft radial displacement.

These are typically mounted through the bearing cap and targeted directly onto the shaft. The sensor system consists of a probe, cable and an oscillator/demodulator (known as a "driver" or "proximitor").

Figure 7. CMSS 68 Eddy Current Probe System

A suitable model is the CMSS 68 series from SKF DYMAC, Figure 7.

The probes have a linear frequency range from DC to 10 kHz. The RYTON™ tip material allows the probe to withstand temperatures up to 177°C (350°F), and differential pressures to 414 Kpa (60 psi).

The voltage output of 8mV/mm is used owing to the relatively short cable run from the engine to the control package. This is passed through an MTL5031 galvanic separator at 1V/V transfer function.

Speed Sensors

Magnetic speed sensors would be provided by the OEM on the high pressure and low pressure shafts of the Gas Turbine Generator, and the output of the Power Turbine.

Machine Protection – LM5000

An GE IDM compliant machine protection monitor system for the LM5000 is the VM600. The system uses a single MPC-4 universal, digital, protection module. This module was specifically designed for gas turbine use, from transducer input, through signal conditioning and processing, to shutdown relay contact closure.

Figure 2 illustrates a system. The entire LM5000 driven train may be protected by three or four identical MPC-4 cards.

Optional redundant power supplies are employed for the highest integrity, and a CPU-M display unit also provides dual serial and/or Ethernet connections to a TCS/DCS/PLC.

VM600 Monitor Sensor Inputs

Figure 8 shows a VM600 layout for the LM5000 configuration shown in Figure 2. The basic requirement is supplemented with an additional MPC-4 card for mainly tracking "High Pressure Compressor Broad Band" vibration as per GE Service Bulletin.

Slot 3 – "Cross Tracking" Monitor

The MPC-4 in Slot 3 supports the accelerometer on the

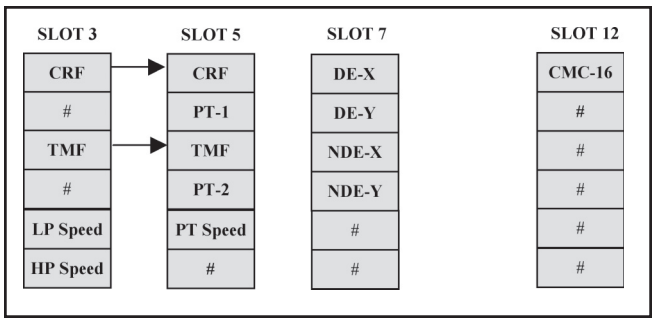

Figure 8. Channel Input Layout for LM5000 DLE with High Pressure Compressor Vibration Modification and CMC-16.

Compressor Rear Frame and the sensor on the Turbine Mid Frame. The input set-up is shown in Figure 9. The Compressor Rear Frame is terminated, powered and conditioned by Input Channel 1, the Turbine Mid Frame by Input Channel 3.

The pick-ups for the Low Pressure and High Pressure spool speeds are supported by Speed Channels 1 and 2 respectively.

Slot 5 – "High Pressure Compressor Broad Band" Monitor

The LM5000 has been found to be prone to high vibration in the High Pressure Compressor (HPC) section. GE recommend that a broad band filter be applied.

Thus the raw signal outputs of the sensors in Slot 3 are routed as inputs to Channels 1 and 3 on Slot 5. The set-up is shown in Figure 10. Note it is identical to Figure 9 with the exception that sensor power is disabled.

The accelerometers mounted within the support struts of the Power Turbine (PT-1 and PT-2) are also terminated on this card, together with the Power Turbine speed pickup. Setup is similar to Figure 9.

Slot 7 – Generator Monitor

This final MPC-4 card is used to monitor the dual X-Y proximity probes used on the generator. Figure 11 shows a typical input set-up. If a phase reference probe ("keyphasor") is fitted on the Power Turbine shaft, this would be supported by the speed channel on this card, with a "1/rev" field selected.

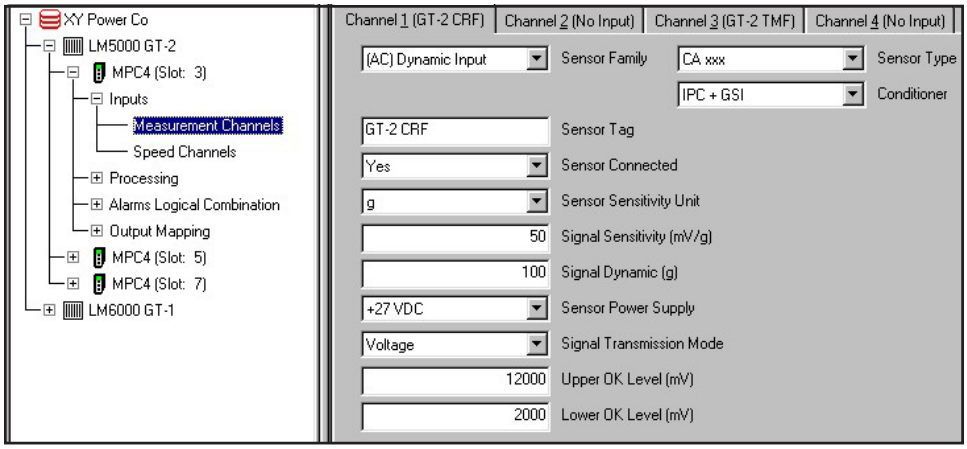

Figure 9. Channel Input Set-up, CRF and TMF Accelerometers.

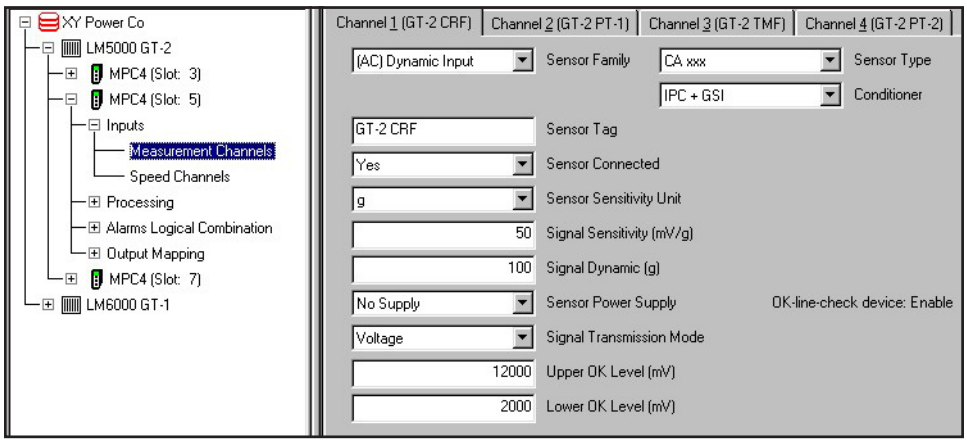

Figure 10. Channel Input Set-up, HPC Broad Band Monitoring.

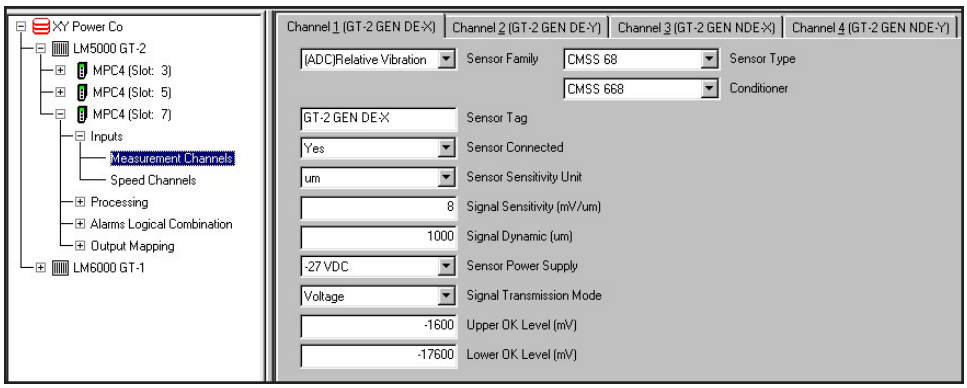

Figure 11. Radial Proximity Probe Set-up Generator.

VM600 Signal Processing for Protection

The processing is defined by the GE Installation Design Manual and is easily configured on an MPC-4 by the Microsoft Windows based MPS-1 configuration software.

The processing used in each MPC-4 is illustrated by Figures 12 – 14.

Cross Track Monitoring

Figures 12 and 15 illustrate the processing for this primary monitoring requirement on an LM5000. A Narrow Band tracking function is programmed for the Compressor Rear Frame signal against 1X Low Pressure speed on Processing

Point	Physical
CRF 1XLP VEL	Channel 1 Output 1
Phase Not Used	Channel 1 Output 2
CRF 1XHP VEL	Channel 2 Output 1
Phase Not Used	Channel 2 Output 2
TMF 1XLP VEL	Channel 3 Output 1
Phase Not Used	Channel 3 Output 2
TMF 1XHP VEL	Channel 4 Output 1
Phase Not Used	Channel 4 Output 2
-------	Channel 1 & 2 Output
-------	Channel 3 & 4 Output
GT-2 LP RPM	Speed Channel 1
GT-2 HP RPM	Speed Channel 2

Figure 12. Slot 3 Processing.

Point	Physical
CRF BB VEL	Channel 1 Output 1
CRF BB ACC	Channel 1 Output 2
PT-1 1XPT VEL	Channel 2 Output 1
Phase Not Used	Channel 2 Output 2
TMF BB VEL	Channel 3 Output 1
TMF BB ACC	Channel 3 Output 2
PT-2 1XPT VEL	Channel 4 Output 1
Phase Not Used	Channel 4 Output 2
-------	Channel 1 & 2 Output
-------	Channel 3 & 4 Output
GT-2 PT RPM	Speed Channel 1
-------	Speed Channel 2

Figure 13. Slot 5 Processing.

Point	Physical
DE-X micron P-P	Channel 1 Output 1
DE-X Gap	Channel 1 Output 2
DE-Y micron P-P	Channel 2 Output 1
DE-X Gap	Channel 2 Output 2
NDE-X micron P-P	Channel 3 Output 1
NDE-X Gap	Channel 3 Output 2
NDE-Y micron P-P	Channel 4 Output 1
NDE-Y Gap	Channel 4 Output 2
DE Smax	Channel 1 & 2 Output
NDE Smax	Channel 3 & 4 Output
GT-2 PT RPM	Speed Channel 1
-------	Speed Channel 2

Figure 14. Slot 7 Processing.

Channel 1, and against 1X High Pressure speed on Processing Channel 2.

The Output 1 of each signal is in RMS velocity (mm/sec or ips) , the second output defaults to Phase Angle and is not used (no single pulse-per-revolution phase reference). The same is repeated on Channels 3 and 4 for the Turbine Mid Frame signal.

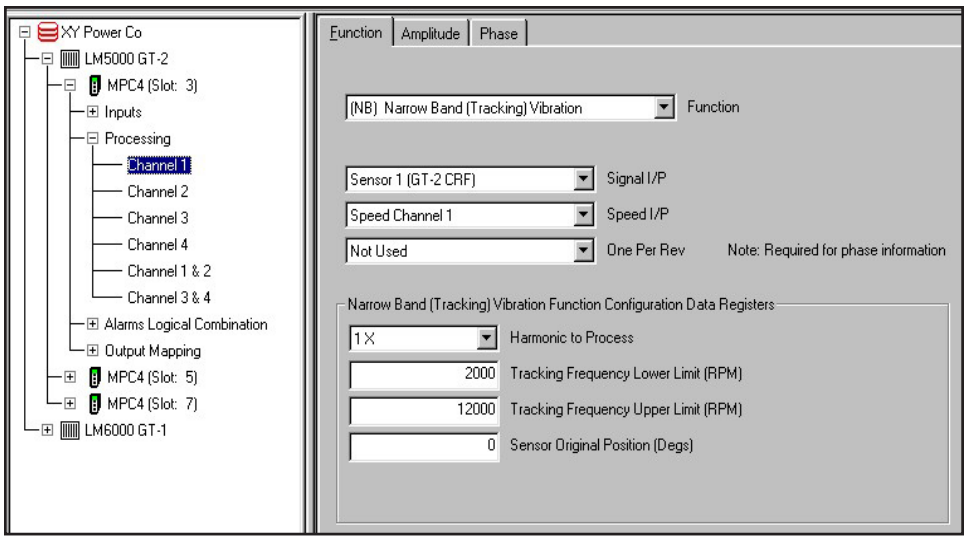

Figure 15. Narrow Band Processing – Compressor Rear Frame and Turbine Mid Frame "Cross Tracking".

High Pressure Compressor Broad Band Monitoring

Figures 13 and 16 illustrate the Broad Band processing. For both Compressor Rear Frame and Turbine Mid Frame signals, Processing Channels 1 and 3 perform Broad-Band Monitoring in the range 25 Hz to 350 Hz. This is to capture acoustic phenomena at frequencies outside the High Pressure and Low Pressure spool running speed frequencies. Figure 16 illustrates the processing screen. The Output 1 of each signal is in RMS velocity (mm/sec or ips), Figure 17. The second Output 2 is in RMS acceleration (g).

Relative Vibration Monitoring

The generator is monitored for normal "X-Y" radial displacement on all four processing channels. The Output 1 of each signal is in Peak-to-Peak Displacement (mm or mils), the second output defaults to the gap (mm or mils or volts). If a keyphasor probe is present, then the Dual Channel processing functions can be used to provide an Smax value.

Alert and Danger (Shutdown) Levels

The Installation Design Manual from GE provides a guide to Alert and Danger levels. However, each installation will choose whether or not to implement a trip function, and will tailor Alert and Danger (shutdown) set-points for each unit. The following is typical:

Broad Band Processing (25 Hz to 350 Hz band)

Alert: 50 mm/sec (2.0 ips) RMS

Danger: 75 mm/sec (3.0 ips) RMS

Note the levels are much higher than that expected on other machines – this reflects the relatively flexible nature of aeroderivative gas turbine construction.

Shutdown Relay Output Logic

Machine shutdown based on any processed variable is actuated via a common or individual relay output, using either the four relays situated on the IOC-4 card, or additional relays on a 16 channel RLC-16 relay card. The logic programming of the MPC-4, using "Basic" and "Advanced "functions, can lead to a large number of possible voting configurations.

A simple requirement is for a common "Danger" (shutdown), "Alert", "Sensor OK" and "MPC Diagnostics" relay for each card. This is illustrated in Figure 18.

Machine Condition Monitoring – LM5000 Fleet

The VM600 permits addition of parallel data acquisition for condition monitoring in the same monitor chassis as that provided for protection, hence ensuring high system integrity without compromising the machine safeguarding function. Any number of 16-channel CMC-16 cards may be placed in any of the 12 available slots, see Figure 19.

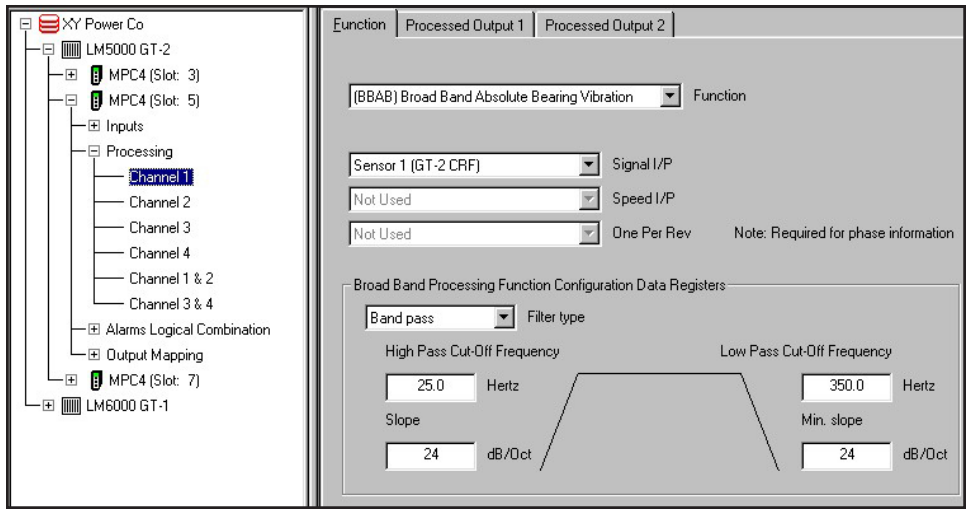

Figure 16. "High Pressure Compressor Broad Band" Processing.

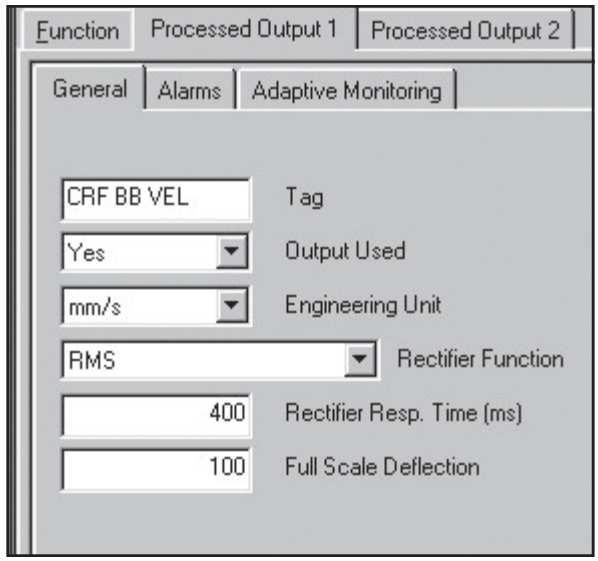

Figure 17. Velocity Output Processing, Compressor Rear Frame and Turbine Mid Frame.

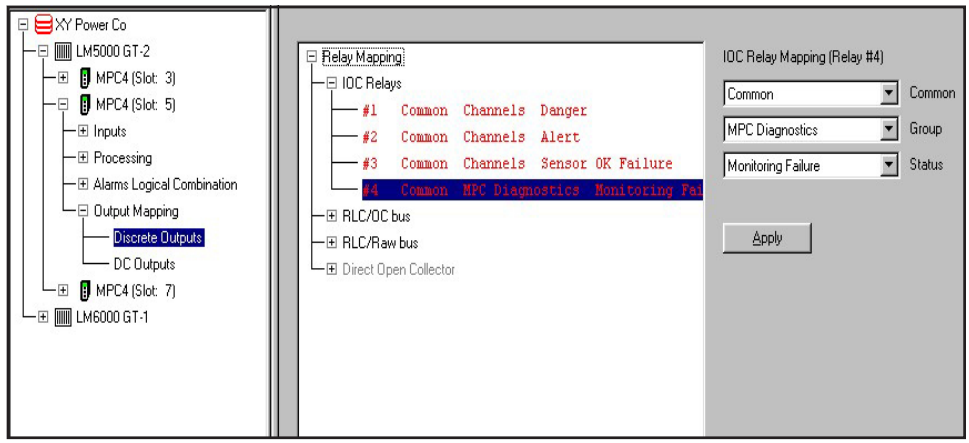

Figure 18. Common IOC Relay Output.

Each channel can process and monitor up to 10 spectral bands. The philosophy of condition monitoring of these critical machines is Multi-Parameter Monitoring. That is, the same input signal is processed in different ways in parallel, in order to determine different characteristic vibration parameters. Each parameter may reveal something different about deteriorating engine condition over time.

The CMS-1 software, Figure 20, is particularly suited to monitoring multiple racks that could be only a few meters apart, or located at remote sites hundreds of kilometers away. The bandwidth typically available on an existing LAN or WAN is sufficient for operation of a centralized server computer.

During transient conditions, the FFT and bands would be monitored closely in order to identify phenomena including:

- High vibration amplitudes
- Combustion Chamber resonance
- External equipment stress/fretting
- Spool nX harmonics
- Bearing defect frequencies

During normal running conditions, the FFT and bands would be monitored periodically to watch for fluctuations in vibration levels, which can occur during low-, part-, or variable-load conditions.

Figure 19. Parallel FFT Data Acquisition CMC-16.

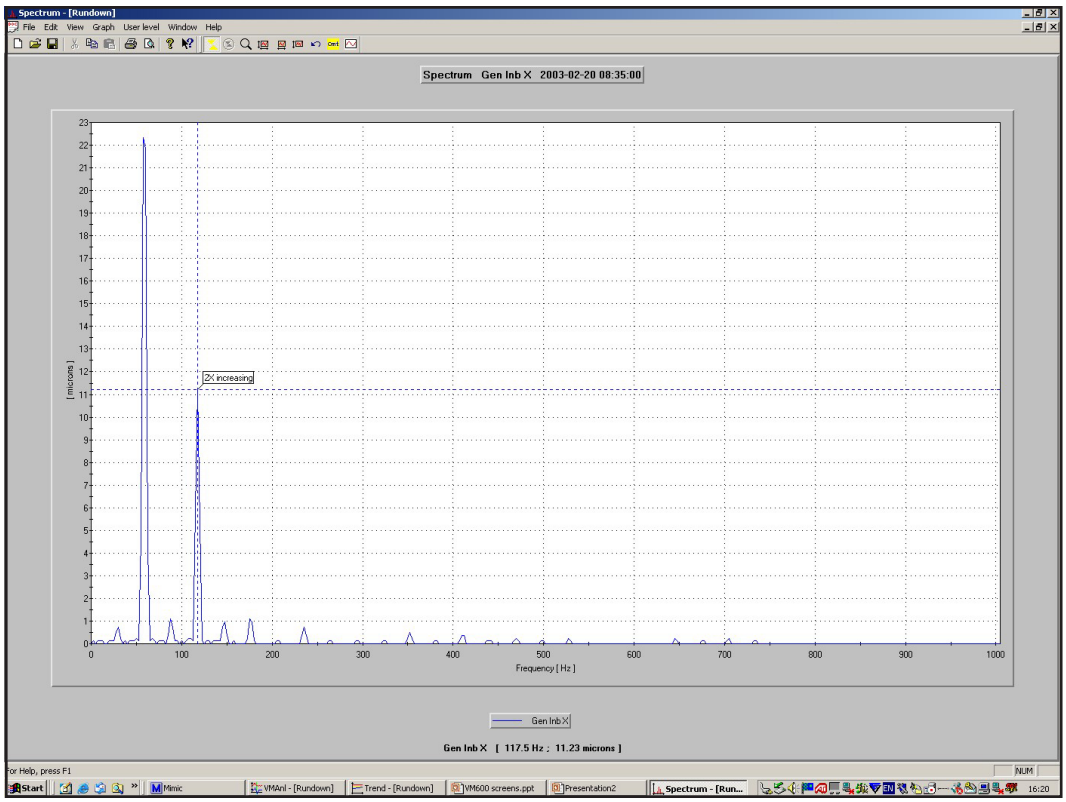

Figure 20. Transient Analyst Software CMS-1, FFT Spectrum Plot.

SKF®

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DYMAC

Item	Qty	Model	Product Number	Description
		SENSORS		**CRF and TMF Accelerometer Chain**
1	1	CA 303	144-303-000-311	CRF Accelerometer, -54°C to +455°C(+850°F), 50 pC/g, 1.22m (48") integral MI cable with stainless steel overbraid and M83723/89Y1020-7 connector
2	1	CA 303	144-303-000-221	TMF Accelerometer, -54°C to +455°C(+850°F), 50 pC/g, 2.06m (81") integral MI cable with stainless steel overbraid and M83723/89Y1020-6 connector
3	2	GSI 130	244-130-000-204	Galvanic separation and power supply unit for piezoelectric measuring chain, 2-wire current transmission. 4kV input/output insulation, dynamic transfer 1 V/mA.
				PT-1, PT-2 Strut Accelerometer Chain
4	1	CA 175	144-175-000-101	PT Accelerometer, -54°C to +400°C(+750°F), 50 pC/g, 4.04m (159") integral MI cable for LM5000
5	1	CA 175	144-175-000-201	PT Accelerometer, -54°C to +400°C(+750°F), 50 pC/g, 3.11m (122") integral MI cable for LM5000
6	2	GSI 130	244-130-000-204	Galvanic separation and power supply unit for piezoelectric measuring chain, 2-wire current transmission. 4kV input/output insulation, dynamic transfer 1 V/mA.
				Generator Bearing Radial Vibration (X-Y) Chain
7	4	CMSS68	CMSS 68-000-00-12-10	Probe, 8mm, 3/8-24 Thread, 1.2" to 6.0" Case Length, 1m Cable.
8	4	CMSS958	CMSS 958-00-040	Extension Cable, 4.0m Length.
9	4	CMSS665	CMSS 668	Driver, 200mV/mil (8mV/µm), +/- 5%, 4140 Steel, 90mil (2.3 mm) Range, 5m System.
10	4	Barrier	MTL 5031	Galvanic Separation for 3-wire Eddy Current Probe System
		MONITOR HARDWARE & SOFTWARE - PROTECTION		
11	1	ABE-040	204-040-100-012	Standard 19" Rack 6U high with VME backplane.
12	1	PLP-960	200-582-960-011	Backpanel with status relay, 2x switch & 2x IEC connectors+cables, dual AC mains input
13	2	RPS-6U	200-582-500-014	Power supply unit (max. 2 per rack). Mains input 90 to 264 VAC
14	1	CPU-M	200-595-033-111	CPU-M with front panel display, Single RS232/485 and Ethernet Configuration
15	1	IOC-N	200-566-000-HHh	I/O card for CPU-M with 2 xRJ45 and 5x RJ11 connectors for single/redundant Ethernet
16	3	MPC-4	200-510-SSS-HHh	Machinery Protection Card, for 4 dynamic and 2 phase reference channels
17	3	IOC-4T	200-560-000-HHh	6 channel in- and output card for MPC with screw terminals. 4 x relays
18	1	RLC-16	200-570-000-HHh	Relay card with 16 relays with change over contacts
19	1	MPS-1	209-500-100-013	Software package for configuration of MPC-4. RS232 point to point connection or Ethernet network. Provides local and remote access. Microsoft Windows (98, NT, 2000, XP), English, French or German
20	4	Config	DMFS-CON	Customer Specific Configuration & Testing. Per card (MPC 4, AMC 8, RLC 16, CMC 16)
		MONITOR HARDWARE & SOFTWARE - CONDITION MONITORING		
21	1	CMC-16	200-530-SSS-HHh	Condition Monitoring Card, for up to 16 dynamic / process channels, up to 4 which can be tacho / phase reference channels. Provides advanced FFT analysis, band extraction, processing and level checking (max. 12 per rack)
22	1	IOC-16T	200-565-000-HHh	16 channel in- and output card for CMC with screw terminals, and multidrop RS485 ports for serial networking. (1 required per CMC 16, max. 12 per rack).
23	1	CMS-1	209-500-600-SSs + Code	Condition Monitoring Software Package for Transient Vibration Analysis with CMC 16 Hardware. Microsoft Windows 98,NT,2000 and XP Operating System. Sybase SQL Database Server Licence and 5 Concurrent User Client Display
24	1	Config	DMFS-CON	Customer Specific Configuration & Testing. Per card (MPC 4, AMC 8, RLC 16, CMC 16)

Figure 21. LM5000 Monitoring System Components.

CM3082 (7-03)