Protection and Condition Monitoring of the LM5000 Gas Turbine

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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.

LM5000 Vibration Monitoring Upgrades

SKF DYMCA 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.
**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 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.
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 1 V/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...
A suitable model is the CMSS 68 series from SKF DYMACK, 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
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.

**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
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.

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.
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.
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“Protection and Condition Monitoring of the LM5000 Gas Turbine”

<table>
<thead>
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<th>Product Number</th>
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<td>1</td>
<td>1</td>
<td>CA 303</td>
<td>144-303-000-311</td>
<td>CRF Accelerometer, -54°C to +455°F (+250°C), 50 pC/g, 1.22m (48&quot;) integral MI cable with stainless steel overbraid and M83723/89Y/1020-7 connector</td>
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<td>2</td>
<td>1</td>
<td>CA 303</td>
<td>144-303-000-221</td>
<td>TMF Accelerometer, -54°C to +455°F (+250°C), 50 pC/g, 2.06m (8&quot;) integral MI cable with stainless steel overbraid and M83723/89Y/1020-6 connector</td>
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<td>3</td>
<td>2</td>
<td>GSI 130</td>
<td>244-130-000-204</td>
<td>Galvanic separation and power supply unit for piezoelectric measuring chain, 2-wire current transmission. 4kV input/output insulation, dynamic transfer 1 V/mA.</td>
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<td>4</td>
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<td>CA 175</td>
<td>144-175-000-101</td>
<td>PT Accelerometer, -54°C to +400°C (+750°F), 50 pC/g, 4.04m (159&quot;) integral MI cable for LM5000</td>
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<td>5</td>
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<td>CA 175</td>
<td>144-175-000-201</td>
<td>PT Accelerometer, -54°C to +400°C (+750°F), 50 pC/g, 3.11m (122&quot;) integral MI cable for LM5000</td>
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MONITOR HARDWARE & SOFTWARE - PROTECTION

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<tr>
<td>11</td>
<td>1</td>
<td>ABE-040</td>
<td>204-040-100-012</td>
<td>Standard 19&quot; Rack 6U high with VME backplane.</td>
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<tr>
<td>12</td>
<td>1</td>
<td>PLP-960</td>
<td>200-582-960-011</td>
<td>Backpanel with status relay, 2x switch &amp; 2x IEC connectors+cables, dual AC mains input</td>
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<tr>
<td>13</td>
<td>2</td>
<td>RPS-6U</td>
<td>200-582-500-014</td>
<td>Power supply unit (max. 2 per rack). Mains input 90 to 264 VAC</td>
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<td>14</td>
<td>1</td>
<td>CPU-M</td>
<td>200-595-033-111</td>
<td>CPU-M with front panel display, Single RS232/485 and Ethernet Configuration</td>
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<tr>
<td>15</td>
<td>1</td>
<td>IOC-N</td>
<td>200-566-000-HHh</td>
<td>I/O card for CPU-M with 2 xRS45 and 5x RJ11 connectors for single/redundant Ethernet</td>
</tr>
<tr>
<td>16</td>
<td>3</td>
<td>MPC-4</td>
<td>200-510-SSS-HHh</td>
<td>Machinery Protection Card, for 4 dynamic and 2 phase reference channels</td>
</tr>
<tr>
<td>17</td>
<td>3</td>
<td>IOC-4T</td>
<td>200-560-000-HHh</td>
<td>6 channel in- and output card for MPC with screw terminals, 4 x relays</td>
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<tr>
<td>18</td>
<td>1</td>
<td>RLC-16</td>
<td>200-570-000-HHh</td>
<td>Relay card with 16 relays with change over contacts</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>MPS-1</td>
<td>209-500-100-013</td>
<td>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</td>
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<td>20</td>
<td>4</td>
<td>Config</td>
<td>DMFS-CON</td>
<td>Customer Specific Configuration &amp; Testing. Per card (MPC 4, AMC 8, RLC 16, CMC 16)</td>
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MONITOR HARDWARE & SOFTWARE - CONDITION MONITORING

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<td>21</td>
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<td>CMC-16</td>
<td>200-530-SSS-HHh</td>
<td>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)</td>
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<tr>
<td>22</td>
<td>1</td>
<td>IOC-16T</td>
<td>200-565-000-HHh</td>
<td>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)</td>
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<tr>
<td>24</td>
<td>1</td>
<td>Config</td>
<td>DMFS-CON</td>
<td>Customer Specific Configuration &amp; Testing. Per card (MPC 4, AMC 8, RLC 16, CMC 16)</td>
</tr>
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Figure 21. LM5000 Monitoring System Components.