Application Note

Narrow Band Vibration Monitoring of Gas Turbines

Industrial gas turbines

The use of accelerometers for vibration measurement on bearings, casings or structures is best practice on gas turbines. The measurements are often referred to as “absolute” vibration, to compare them against the “relative” measurement of displacement (which is preferred for the vibration measurement of journal bearings). In general, aeroderivative and lighter industrial gas turbines use exclusively absolute measurements, whereas heavy duty gas turbines employ relative measurements. However, the use of accelerometers on heavier machines at selected locations is quite common. When considering absolute measurements, there are three modes of signal evaluation, namely:

- Broadband or reduced band
- Dual path – two or more frequency bands
- Narrow band frequency with tracking filter

This application note discusses the **narrow band** implementation.

Fundamentals of narrow band monitoring

This monitoring mode is a complement to the broadband monitoring, as it allows one to observe the evolution of the amplitude and phase of one or more specific vector components as a function of machine speed.

This is achieved by using a narrow band filter (often termed a “tracking filter”) to synchronize a vector with the once-per-revolution machine speed, or a ratio thereof. Usually the first harmonic, also called the “fundamental frequency”, is taken into account in narrow band monitoring. The narrow band is able to isolate the first harmonic’s information (amplitude and phase angle) from the rest of the frequency spectrum. In order to implement narrow band monitoring, it is necessary to measure the machine speed and a reference point from which the phase angle may be calculated. The process is illustrated in **fig. 1**.

SKF

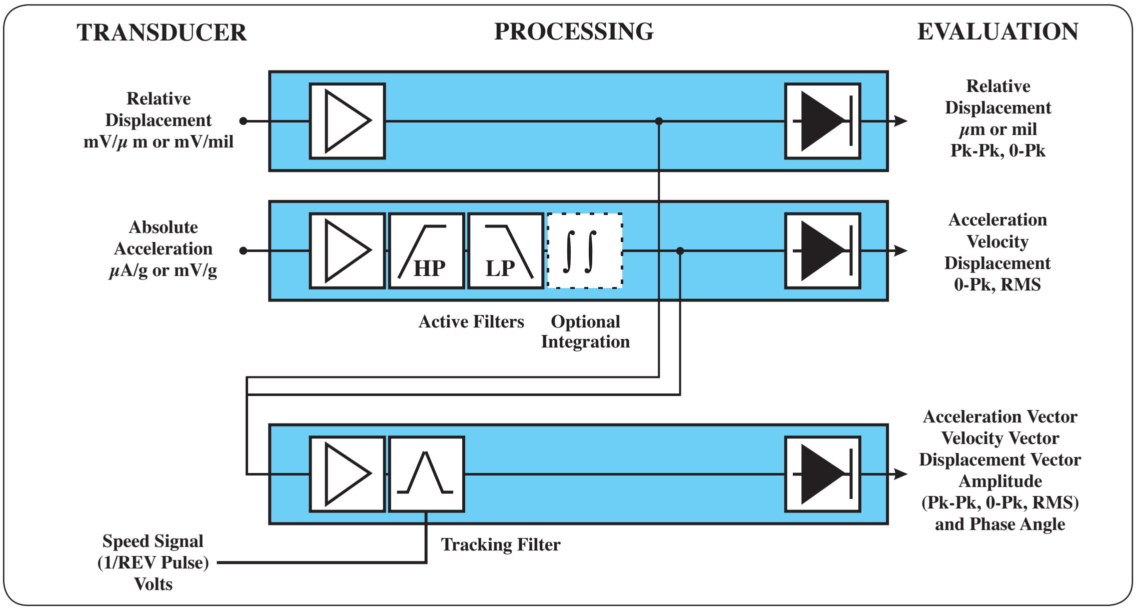

Fig. 1. Signal path – narrow band monitoring.

This extraction of the first harmonic information is particularly useful for machines with several shafts rotating at different speeds. Another benefit is seen on machines that are located on relatively flexible structures, where sources of vibration external to turbine train can have an influence; synchronization to the actual machine eliminates these components.

The main drawback of narrow band monitoring is the necessity for a sensor system on the machine to provide a speed and phase marker. Utilizing a multi-tooth wheel in a gearbox, for example, will provide speed information as a ratio, but cannot give a consistent phase reference; for this, a single event per revolution is needed. The most common approach is to target a keyway on the shaft, typically near a coupling. This leads to the industry term "keyphasor".

Transducers, conditioners and transmission

The choice of transducer, its quality and performance, as well as its location on the machine, are crucial criteria for the efficiency of any vibration monitoring system. The choice of transducer for narrow band monitoring is dictated by two fundamental considerations:

- Environment – particularly safe or hazardous area (Ex i) requirements
- Operating temperatures

The choice of a high frequency accelerometer has the advantage that, besides fulfilling the above criteria, it provides high frequency signals for analysis.

The Vibro-Meter CE type is recommended for Ex i applications with surface temperatures up to 260 °C *(500 °F)*, the attached local electronics being limited to 100 °C *(212 °F)* (or 150 °C *(300 °F)* if a non-Ex i environment).

Vibro-Meter CA type is recommended for non-Ex i applications with surface temperatures up to 650 °C *(1 200 °F)*, with an IPC-704 charge amplifier mounted in a cooler zone. An optional integrator within the IPC-704 can covert the signal from acceleration to velocity.

The main factors that limit the temperature a transducer can withstand is the location and quality of its signal conditioning electronics. As in the case of dual path monitoring, it is important that there be as little attenuation as possible of the higher frequency components of the vibration signal.

To achieve this, a current modulated signal (µA/g) is used for transmission of the signal to its associated monitoring electronics; **fig. 2** illustrates this. The CE type model provides a current modulated output from its attached electronics. The CA type model provides a current modulated output from the charge amplifier model IPC-704. The µA/g output can be transmitted over distances between 1 000 to 2 000 m *(0.6 to 1.2 mi.)* without significant signal attenuation.

The final consideration is the sensor for speed and phase marker. The most common approach is to utilize the same sensor type employed in relative shaft vibration measurements, an eddy current probe. In these applications, access to the shaft (to target a suitable once-per-revolution event) is frequently restricted, so a 5 mm tip diameter probe is preferred. The CMSS 65 series from SKF is recommended. The CMSS 65 probe cable would either be connected directly to its CMSS 665 oscillator/demodulator (or "driver") or by means of a CMSS 958 extension cable. A CMSS 665-16-9 driver would be required for Ex i installations. The most common configuration is a matched electrical length of 5 m *(16.4 ft.)*. The upper temperature limit for the probe is 177 °C *(350 °F)*, and 70 °C *(158 °F)* for the driver. Transmission to the monitoring system is by voltage. An eddy current probe signal has two voltage components, AC (mV/mil) and DC gap (Volts). For a Keyphasor, only the DC voltage is of interest.

All the above factors mean that the choice of sensor is evaluated in great detail by the gas turbine manufacturer and approved as fit-for-purpose by engine type. **Table 1** shows a table of engine types that employ narrow band monitoring, with approved sensors.

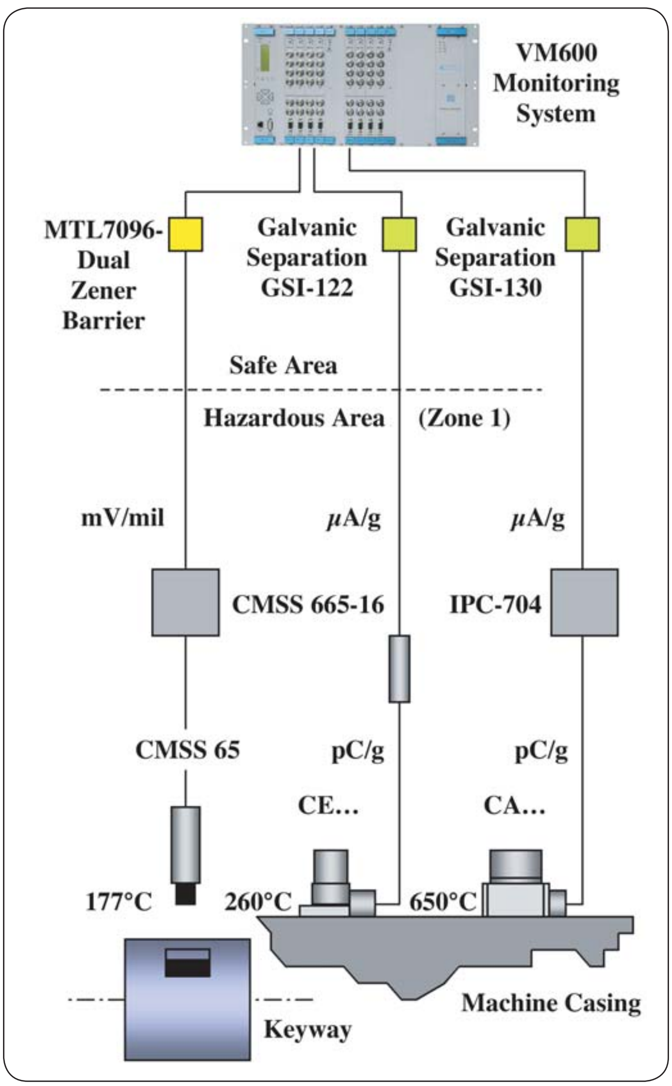

Fig. 2. Accelerometer and phase reference measurement chains.

Table 1

Industrial gas turbines using narrow band monitoring

Manufacturer	Type	Transducer	Conditioner	Electronics
Rolls-Royce	RB211	CE134		Vibro-Meter MMS Manufacturer specified system
Rolls-Royce	Avon	CE134		Vibro-Meter MMS
Rolls-Royce	Spey Marine Version	CE134 CA902		Vibro-Meter MMS
Turbomeca	Bastan VII	CE136		Vibro-Meter MMS

Example application

Typical example applications of narrow band monitoring are on-board gas turbines (jet or ship propulsion) or offshore power generation or gas compression trains.

Fig. 3 is a measurement point diagram of an IHI/GE Type LM5000 gas turbine driving a turbo-alternator. Three measuring chains monitor the gas turbine generator: two on the compressor section, the third on the turbine section. A fourth sensor monitors the power turbine.

Two measuring trains monitor the generator, the transducers being mounted on the bearing caps. Two phase marker chains target the two shafts, fore and aft of the machine.

The whole system is six-channel monitoring, measuring both dual path and narrow band implementations. The four sensors on the gas turbine train employ both broadband and narrow band monitoring. The tracking filters of the first three chains are synchronized with the first harmonic of the high pressure spool of the gas generator. The filter of the fourth chain is synchronized with the power turbine's shaft, which directly drives the alternator. The two alternator sensors use broadband monitoring only.

Two different transducers are employed. The Vibro-Meter CA 905 is used on the hot parts and is rated to 620 °C *(1 148 °F)*. The remainder employ a Vibro-Meter CA 201, which is rated to 260 °C *(500 °F)*.

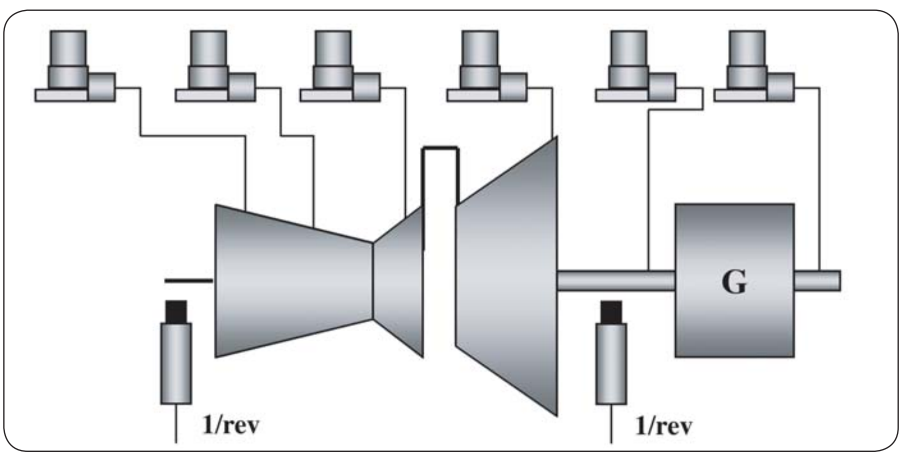

Fig. 3. Example application.

Processing and evaluation

The evaluation of the sensor signal in a narrow band application follows the principle of **fig. 1**. A broadband evaluation of each signal is normally realized using an RMS velocity parameter (mm/sec) over 10 to 1 000 Hz. For a narrow band evaluation, the peak velocity (mm/sec) of the amplitude of the first harmonic is displayed, together with its associated phase angle (degrees). The amplitude and phase of the first harmonic are the basic parameters required to balancing. If the monitored machine has accessible balancing planes, the information provided by the narrow band processing facilitates in-situ balancing of the rotor. The evaluation takes place in a monitoring system such as the VM600 system illustrated in **fig. 2**.

The VM600 system assigns a single filter or function per channel, and allows two subsequent processed output paths within that filter or function. Hence, to employ both broadband and narrow band monitoring from the same sensor, two channels must be employed in parallel. **Fig. 4** shows the measurement channels for the first MPC-4 card in the application. The forward accelerometer on the Gas Generator compressor section (GG COMP FWD) is wired to Measurement Channel Number 1. The aft accelerometer on the Gas Generator compressor section (GG COMP AFT) is wired to Measurement Channel Number 3. Measurement Channel Number 2 and Number 4 are unused.

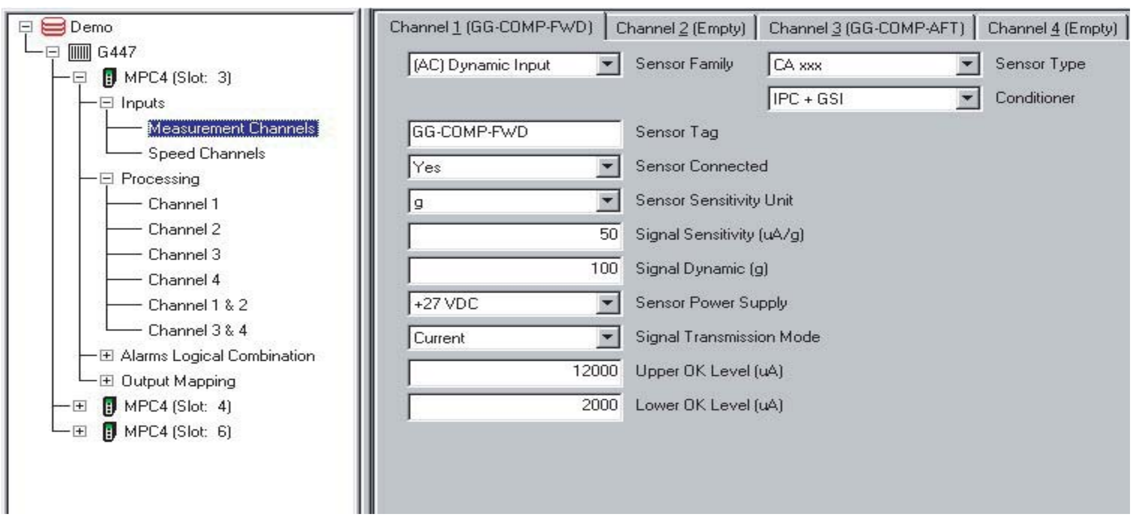

Fig. 4. VM600 input programming for example narrow band application.

The output signal of Measurement Channel Number 1 (GG COMP FWD) is routed by programming to the inputs of both Processing Channel Number 1 and Processing Channel Number 2 (→ **figs. 5** and **6**).

Fig. 5 shows that Processing Channel Number 1 is set to a broadband monitoring function with a 10 to 1 000 Hz filter. Its "Processed Output 1" is set to mm/sec RMS. The "Processed Output 2" is unused. The velocity output would have two alarm set-points defined, ALERT and DANGER. The latter may be used for machine shutdown, in order to protect it from excessive vibration levels. This is done by mapping the velocity DANGER output to a relay contact.

The narrow band processing is accommodated by Processing Channel Number 2 (→ **fig. 6**). The signal from Measurement Channel Number 1 is first selected. Then the relevant speed channel is assigned in order to synchronize with a once-per-revolution reference. The required harmonic, in this case the first (1x), is then specified. When narrow band processing is selected, the "Processed Outputs" default to Amplitude (→ **fig. 7**) and Phase Angle (→ **fig. 8**).

The above setup would be repeated for the Gas Generator compressor section aft, Gas Generator turbine section (GG TURB) and Power Turbine (PT AFT). The two alternator channels would be assigned to broadband monitoring in a similar manner to **fig. 5**.

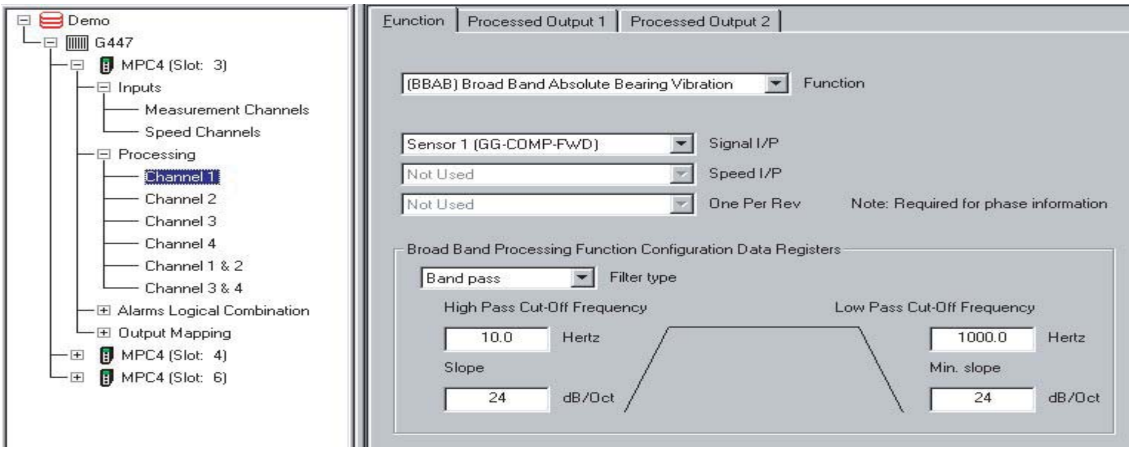

Fig. 5. VM600 processing programming for broadband component.

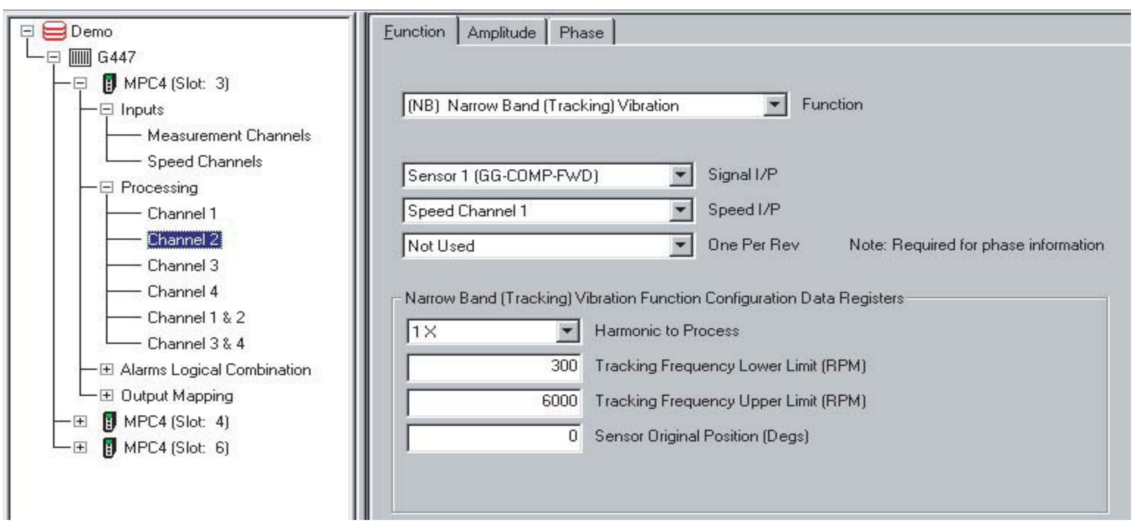

Fig. 6. VM600 processing programming for narrow band tracking filter channel.

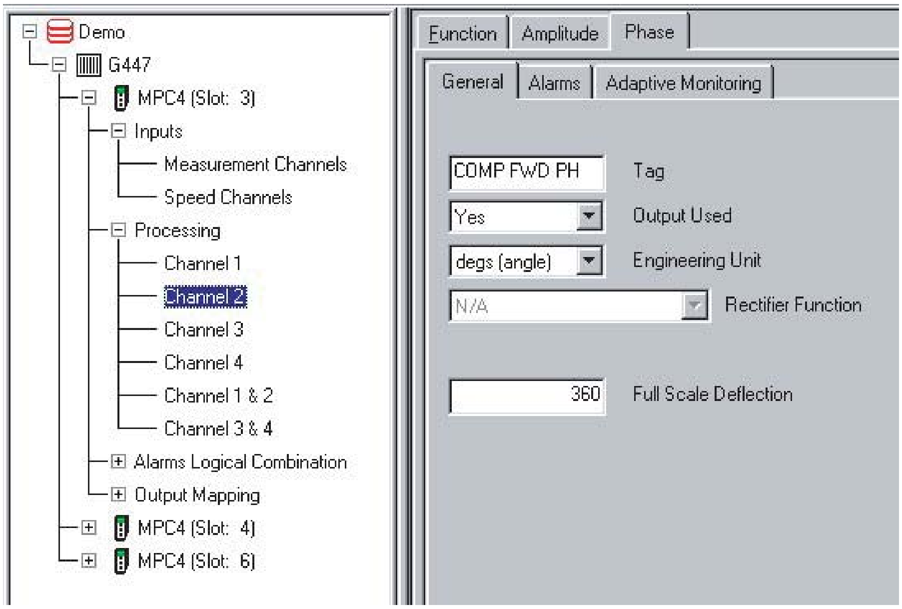

Fig. 7. VM600 processing programming for 1x amplitude.

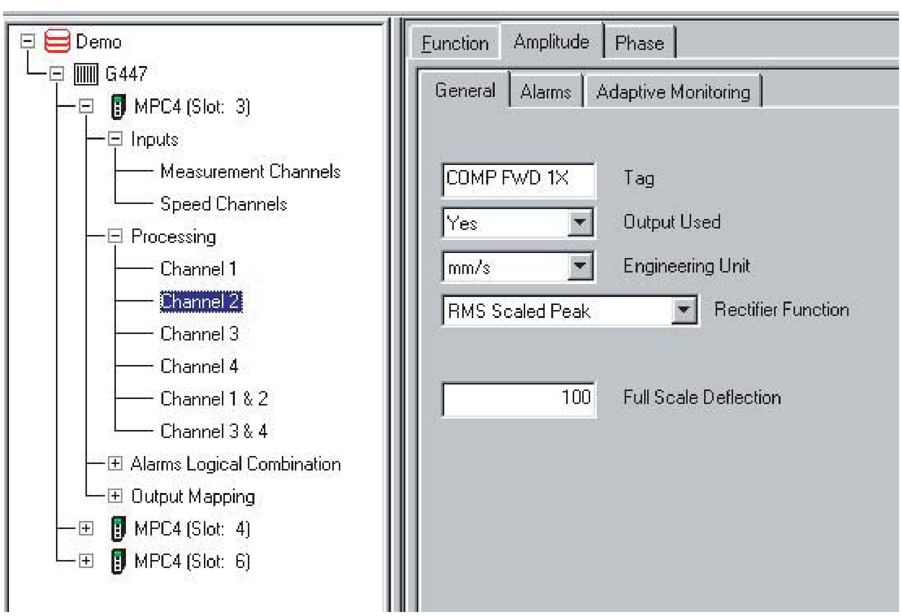

Fig. 8. VM600 processing programming for 1x phase angle.

The VM600 is a multi-channel digital monitoring system, with a single monitor card (the MPC-4) fully programmable for virtually all applications. Each MPC-4 card supports four dynamic channels and two speed channels. Considering the above programming, the VM600 protection hardware required for the example in **fig. 3** is three MPC-4 cards:

MPC-4 Card Slot Number 3:

- Channel 1.1 Gas Generator Compressor Forward Broadband Velocity
- Channel 1.2 Gas Generator Compressor Forward Unused
- Channel 2.1 Gas Generator Compressor Forward Narrow Band 1x Amplitude
- Channel 2.2 Gas Generator Compressor Forward Narrow Band 1x Phase
- Channel 3.1 Gas Generator Compressor Aft Broadband Velocity
- Channel 3.2 Gas Generator Compressor Aft Unused
- Channel 4.1 Gas Generator Compressor Aft Narrow Band 1x Amplitude
- Channel 4.2 Gas Generator Compressor Aft Narrow Band 1x Phase
- Channel 5.1 High Pressure Spool Speed
- Channel 6.1 Speed-2 Unused

MPC-4 Card Slot Number 4:

- Channel 1.1 Gas Generator Turbine Broadband Velocity
- Channel 1.2 Gas Generator Turbine Unused
- Channel 2.1 Gas Generator Turbine Narrow Band 1x Amplitude
- Channel 2.2 Gas Generator Turbine Narrow Band 1x Phase
- Channel 3.1 Power Turbine Broadband Velocity
- Channel 3.2 Power Turbine Unused
- Channel 4.1 Power Turbine Narrow Band 1x Amplitude
- Channel 4.2 Power Turbine Narrow Band 1x Phase
- Channel 5.1 Power Turbine Speed
- Channel 6.1 Speed-2 Unused

MPC-4 Card Slot Number 6:

- Channel 1.1 Alternator Inboard Broadband Velocity
- Channel 1.2 Alternator Inboard Unused
- Channel 2.1 Alternator Outboard Broadband Velocity
- Channel 2.2 Alternator Outboard Unused
- Channel 3.1 Spare Unused
- Channel 3.2 Spare Unused
- Channel 4.1 Spare Unused
- Channel 4.2 Spare Unused
- Channel 5.1 Speed-1 Unused
- Channel 6.1 Speed-2 Unused

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