Digital Bus Based Vibration Sensors "Migrating the Test Cell Inflight"

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ABSTRACT

Aviation and Industrial machinery diagnostics is entering a new era, with new urgency, as industry moves toward better asset management and eventually to unmanned operations. Owners and operators are expecting the advanced machines of the future to have the ability to self-diagnose conditions that could lead to catastrophic failure or to unanticipated down time. Next-level, algorithm-driven associations to yield, machine efficiency, and other operating characteristics that can be defined in terms of the "energy" associated with known machine processes can also be translated into useful parameters for transmission over a digital data bus. To reach those goals, a new technology platform has been introduced to enable the next generation of smarter machines. Advanced sensors with on-board digital signal processing (DSP) features are the key to this new machine "awareness". The advent of smaller, more powerful microprocessors enables a new generation of bus-based digital vibration sensors to process and reduce analog data inside the sensor itself. The new technology eliminates the long wire runs to each sensor commonly associated with traditional analog test cell arrangements and replaces it with a single-cable, all-digital bus-based schema. In addition, the improved system architecture provides reduced SWaP (size, weight & power) of traditional onboard VHM (vibration health monitoring) systems, easier troubleshooting and more importantly, distributed processing.

1.0 CAN-MD® TECHNICAL BACKGROUND

1.1 Introduction

Vibration sensors (unlike temperature, pressure, inertia, load, and other relatively slowly changing physical measurement factors) produce incredible volumes of dynamic data. Streaming raw dynamic vibration data down a bus is not possible given the limitations of digital bus processing speeds. Dynamic vibration sensors capable of sophisticated machinery diagnostic functions have remained all-analog and have not transitioned to digital bus communications; they remain as one of the last major unsolved machinery sensing challenges. Digital solutions offer simpler wiring schemes, shorter sensor cable runs, and user-configurable firmware to optimize each monitoring location for the best possible results. Digital sensors offer a flexible, scalable platform on which to host diagnostic applications in a bussed environment. Embedded sensors must be small and robust, capable of withstanding demanding environments and yet offer years of dependable operation.

To replicate machinery diagnostics done in a traditional test cell, data must be processed at the sensor level while using a data bus as a way to transmit the processed data.

1.2 Data and Condition Indicators

Condition Indicator (CI) is the result, or the processed data, that is provided as an output on the data bus. No longer is a complicated central DSP system needed to process the raw data from analog accelerometers. The sensors themselves process the data. In order to perform their duties, the sensors need to know some setup information. They need to know when to take data. Do they take it all the time or do they respond to a command? Do they report raw data / intermediate data or just results? The answer is yes to it all. Each sensor can boot up and start collecting and processing CIs automatically. These CIs can later be filtered with additional information to classify "operating mode" dependent results. Sensors can respond to commands over the data bus. These commands can be an order to collect and output raw data on the data bus. Raw vibration data can be requested from a particular sensor and stored on a data logger or user's commands via an avionics interface. This raw data is not typically stored on a daily basis due to the file size and transfer times, but it is tremendously useful in debugging or analysing difficult vibration problems.

Additionally, a critical design aspect is that each sensor has its own address and the setup configuration is stored at the sensor level rather than on a central processor in an external LRU. It will then be infinitely easier to identify which sensor a particular CI is assigned to during installation testing and fielding of the product.

1.3 Digital Sensor Description

Figure 1-1 shows some examples of rugged accelerometers alongside an in-line bus adaptor that is used to convert standard IEPE (Integrated Electronic Piezoelectric) accelerometers and output the processed information onto the bus. The accelerometers and adapter feature the aircraft-industry approved D38999 self-locking connector for enhanced, proven reliability in tough field environments. These designs are hermitically sealed and suitable for a wide variety of harsh machine environments. Where high temperature applications are needed requiring operation in hot areas a traditional "charge mode" type of accelerometer can be adapted utilizing a sensor adapter similar to Figure 1-1 and remote mount the processing outside of the hot area. This approach keeps the analog cable runs as short as possible.

Figure 1-1: Typical CAN-MD® Sensor Configurations

1.4 Theory of Operation – Basic Sensor

CAN-MD® is simply Machinery Diagnostics processed at the sensor level while using digital bus as a way to transmit the processed data. The high-level diagram of the sensor processing flow is shown in Figure 1-2.

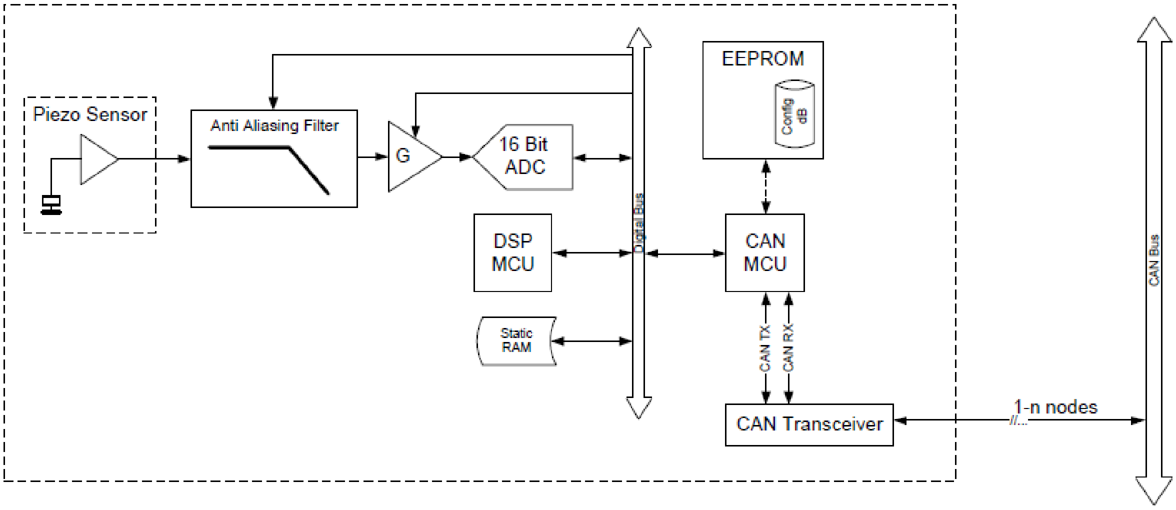

Figure 1-2: CAN-MD® Accelerometer Diagram

- A Piezo based transducer is used to detect vibration along a single axis
- An analog anti-alias filter removes vibration data above the desired bandwidth
- A programmable Gain (auto-gain) circuit amplifies the vibration signal to suitably fit into analog to digital converter range.
- A 16-bit analog to digital converter samples the raw vibration data.
- The DSP MCU is a microcontroller that performs digital signal processing. This is where the spectral data and Condition Indicators are calculated.
- Static RAM is used for volatile data storage.
- EEPROM is a non-volatile data storage area for the sensor configuration database and BIT test results.
- The CAN MCU is a microcontroller that communicates with the CAN Transceiver and passes raw and processed vibration data to the bus and receives messages from the bus.
- The CAN transceiver packages data and communicates with the CAN v2.0b bus.

Configuration information is stored in the sensor in non-volatile memory. This setup information contains the parameters of how to make the measurements and when to make the measurements. This enables the sensor to start collecting data automatically or to respond to measurement commands from another device on the CAN bus. The sensor can be configured to simply collect and store raw time domain data or process the data in the frequency domain. Typically, the time domain data is used only for initial system setup and advanced diagnostics as this data can be large and bulky. However, other times it is useful for a segment of time data to be collected if an abnormal event is detected and further evaluation is warranted or desired.

Figure 1-3 shows how the sensor processes time domain data into frequency domain data.

Frequency domain data is useful for identifying and tracking specific fault sources by their known operating frequency. The chart on the right side of Figure 1-3 shows a typical frequency domain spectral plot. The CAN-MD® sensor can collect and transmit these spectra as "intermediate" data if desired as long as the sensor is setup to perform this process. The rate at which the sensor collects and transmits frequency domain data is configurable within the firmware.

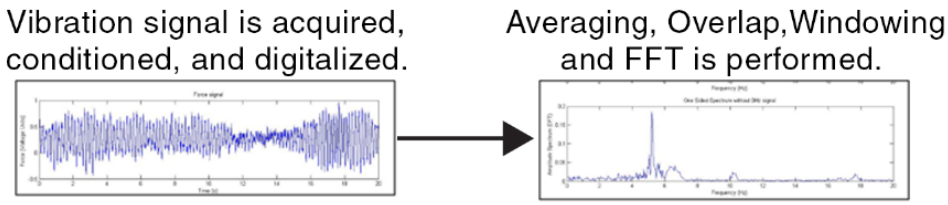

Figure 1-3: CAN-MD® Accelerometer Time Domain Data

Apart from collecting raw time domain data and intermediate frequency domain data, the sensors process features from these data sets to create a Condition Indicator (CI). A CI is usually a feature in the data that is calculated, thresholded and trended for machinery diagnostics. There has been a great deal of interest and science put into the different ways to calculate CIs and relate them to mechanical faults. Some are very basic like the overall RMS value of the time domain data, while others are more complicated using time synchronous averaging processes with related tachometers. This peak can be from an absolute frequency or can be a variable frequency as related from tachometer.

2.0 RESEARCH AND DEVELOPMENT

Dytran Instruments is a leader in digital bused based smart sensors for condition-based monitoring (CBM), and have been leading efforts in platform expansion. We continue developing closely with our integration partners, both inside and outside of the aerospace industry to provide continues improvement for this next generation smart monitoring platform. An example of such development is our efforts with GE Czech for turboprop engine vibration health monitoring.

2.1 CAN-MD® Sensor Fusion

CAN-MD® offers a variety of analog sensor adapters that allow users to add existing sensors to the CAN-MD® network. This extends many of the benefits of the CAN-MD® technology to legacy vibration sensors or other measurement node types. By expanding the measurement input possibilities, it allows the system to provide improved sensor fusion, pulling data from a greater number of nodes to allow users to make data driven decisions based on multiple sensor locations or measurements types. Figure 2-1 shows the variety of currently available sensor adapters includes tachometers, optical blade trackers, IEPE sensors (acceleration, pressure, force) and high temperature charge mode sensors.

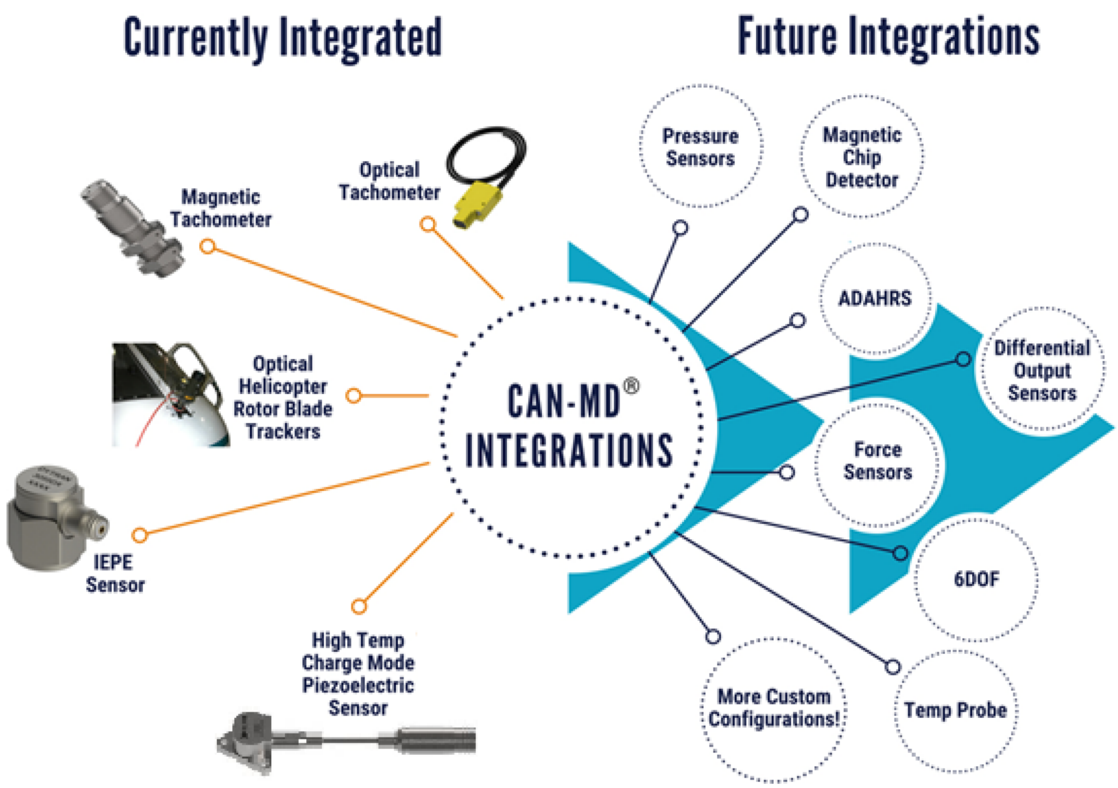

Figure 2-1: CAN-MD® Sensor Fusion

2.2 CAN-MD® Sandbox

The CAN-MD® sensors and adapter are preloaded with user configurable conditions indicators (CI's) that cover the majority of rotating machinery diagnostics. For users that require onboard processing of proprietary or advanced algorithms our team is developing a new capability referred to as the "Sandbox". This will provide users with a separate partitioned hardware directly within the sensor itself which will allow the user to load their own proprietary algorithms thus fully protecting their intellectual data These algorithms would then read the raw sensor data and provide their own calculations and output as "CIs" similar to the standard algorithms resident in the sensor.

The "Sandbox" functionality opens additional opportunities for users to take advantage of this new bus based platform while still allowing users to bring their existing or developed algorithms for machinery diagnostics or prognostics into a new generation of sensors hardware.

2.3 System Integration Development with GE Aviation Czech

A testing campaign at GE Aviation Czech was recently completed, validating the effectiveness of the system for full time vibration health monitoring (VHM) in small turboprop applications. The test series was conducted via a side- by-side comparison using GE's test cell engine data acquisition system. The internally microprocessor-enabled CAN-MD® sensors successfully and accurately acquired, processed and broadcasted the detected vibration signatures onto the digital data bus in the form of Condition Indicators (CIs) that correlate into component faults. Data from CAN-MD® was then integrated with the test cell display and control system for immediate comparison. With vibration processing now being accomplished on the sensor, CAN-MD® fault detection can easily be integrated into existing test cells, aircraft avionics, and flight tracking systems providing for a fulltime lightweight and scalable VHM solution that supports both engine/propeller health and propeller balance while eliminating the need for temporary fit support equipment. During the next phase of testing, CAN-MD® will be installed on a flying testbed using an H80 engine to validate the diagnostics capabilities seen in recent testing. The end target could be the introduction of this solution on the H Series engines with a full integration into the aircraft's avionics to record data relative to the health of the propeller, compressor, turbine, gearbox, and accessories.

Looking ahead, CAN-MD® is ideal for all aircraft operations and especially those flying in agricultural, training, SAR, ISR manned/unmanned where lower system weight is critical to identify impending mechanical issues that could affect vehicle safety, operation and improve maintenance tracking.

3.0 TRANSITION TO PLATFORM

3.1 Turboprop CAN-MD® System Approach

The CAN-MD® technology is applicable to a multitude of condition-based monitoring (CBM) applications. For the purpose of this discussion the example of fixed wing turboprop aircraft integration is discussed. This new "affordable" and "disruptive" technology brings enhanced CBM philosophy to turboprop operations by offering full time monitoring of engine rotating parts, engine accessories and propeller health. The CAN-MD® system is capable of performing propeller balancing and therefore negating the need for portable test equipment saving time and money in upkeep and logistics associated with those systems. Many turboprop aircraft operate in hazardous areas with operations in unimproved airports. Prop strikes from FOD and birds are a real possibility and full-time monitoring can help assess those incidents and assist in early warning of damaged components prior to further collateral damage. CAN-MD® can be integrated into the avionics or be a standalone installation if desired. CAN-MD® offers a new paradigm in fixed wing engine and propeller monitoring not offered before.

CAN-MD® accelerometers install and appear very similar to traditional accelerometers. A minimum installation requires at least one accelerometer and one tachometer monitoring the propeller to be installed on each engine. This minimum setup will provide the information necessary to indicate propeller health, propeller gearbox health and phase/amplitude needed to calculate propeller balance solutions.

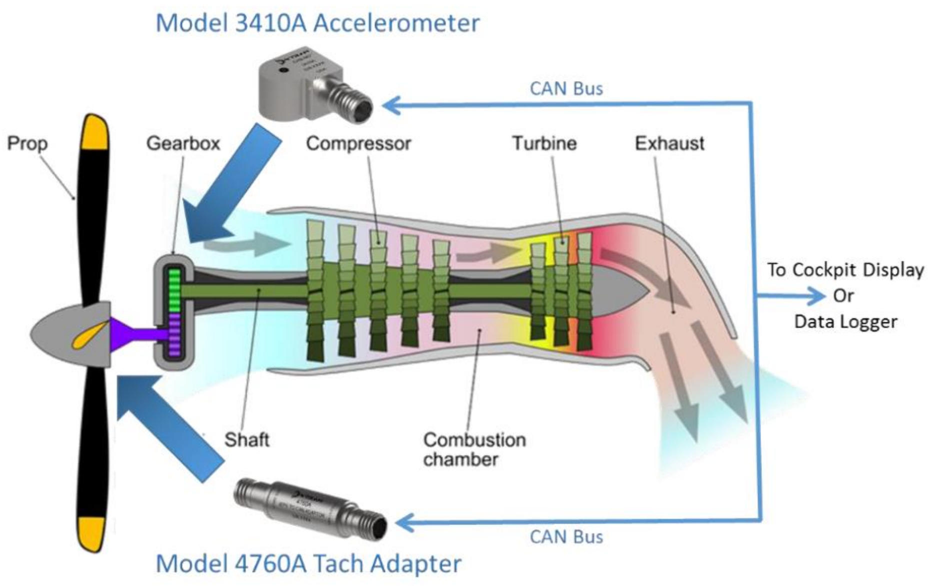

Figure 3-1: CAN-MD® System Diagram

Adding additional accelerometers or tachometers is as simple as plugging another unit into the data bus. Up to 31 appliances can be supported on a single data bus. Allowing the user to start small by only monitoring the propeller or add additional sensors to include advanced diagnostics on gearboxes, compressors, turbines and accessories.

The CAN-MD® system allows for single and multi-engine applications to be handled via a single bus solution or a separate bus per engine. OEM periodic engine vibe monitoring procedures are readily supported and easily integrated into full time monitoring allowing for proactive scheduling of identified faults.

Many engine applications require hi-temperature sensors and CAN-MD® supports high temperature engine vibration monitoring, up to 1200 °F too.

3.2 CAN-MD® - Integrated Cockpit

Since each sensor processes the data at the sensor and outputs the results onto a data bus, integration with the aircraft's avionics can be accomplished with the avionics OEM support. If this component has a CAN bus input utilizing CAN 2.0b hardware then only software changes are needed. If CAN 2.0b hardware is not available additional data bridges are available. For integrators wanting to incorporate the CAN-MD® proprietary protocol an ICD is available that fully documents each sensor operation. Sensor information such as propeller balance (phase/amplitude), gear and bearing health values along with any OEM engine vibe parameters can easily be shown on the cockpit instrumentation. CAN-MD® finds faults before they become a costly nuisance.

3.3 CAN-MD® - Legacy Analog Cockpit

If an aircraft does not have support for a digital data buses, the Model 4763A WiFi data logger records all information from the data bus and stores it for later viewing and archiving. This unit coupled with our Android Tablet PC running the CAN-MD® Android application allows for ready viewing of the vibration and speed data coming from each sensor wirelessly through the WiFi data connection. It will also allow the operator to view previously stored data from past flights too.

Figure 3-2: CAN-MD® WiFi Data Logger

4.0 CONCLUSIONS

This technology can provide reliable health monitoring both in the engine test cell and also integrate well into an airborne environment. Testing has been accomplished in several test cells along with some limited “on-aircraft” testing. All tests were performed against a referee system and the results were equal to and in some cases faster than these systems. Synchronous measurements in addition to the Asynchronous measurements can be used to address on-wing dynamic propeller and turbofan trim balancing negating the need for portable test equipment too. Additional planned feature improvements call for adding a “Sandbox” area allowing “third party” entities such as OEM’s to load their own proprietary algorithms thus fully protecting their intellectual data. These algorithms would then read the raw sensor data and provide their own calculations and output as “CIs” similar to the standard algorithms resident in the sensor. Other uses for the “Sandbox” could be to run remaining useful life (RUL) calculations in the sensor. Additionally, component history information could be stored in the sensor and this data could automatically be updated and new counts added to track starts, cycles and other counts needed for component history information. Theoretically a sensor could be installed at the first run and kept with that module and the entire component history of that module could be stored inside the sensor “cradle to grave”.

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