Application Brief:

Signal Conditioning for Gas Turbine Engine Testing

Introduction:

Designers of measurement systems for gas turbine engine testing deal with a complex set of environmental conditions that challenge their ability to ensure their data is valid. Hundreds of sensors and lead wires are collecting data on pressure, strain, vibration and temperature while interacting with the extremes of these very same conditions. In addition, the test environment is further complicated by the corrosive effects of hot gasses, magnetic fields, and multiple opportunities for noise pick-up. To account for these issues, the implementation of a variety of signal conditioning and wiring techniques is essential to sort out the data from the noise and to ensure that the data is valid.

Precision Filters' 28000 system offers a suite of signal conditioning and amplifier cards designed specifically to address the challenges of the gas turbine engine test environment. Testing is expensive and time consuming; every feature and capability of our signal conditioning system offers our customers the highest level of confidence in the validity of their test data as well as reduced test set-up and troubleshooting time. This application note discusses specific measurement issues and describes Precision Filters' solutions.

Applications:

- Dynamic strain on rotating fan blades
- Spin pits
- Blade-out testing
- Compressor research
- Steam turbine testing
- Power generation testing
- Bird impact testing
- Fan balancing
- Wind turbine testing
- Thrust stands
- Acoustic noise
- Component testing

Strain and Bridge Sensor Conditioning:

The majority of sensors used for research and development testing on gas turbine engines are strain gages. The gages measure strain on both the rotor and stator, often at extreme temperatures and in noisy environments. The measurement of static strain, load, dynamic pressure and acceleration are also common for gas turbine engine tests.

The Precision 28144 quad channel conditioner provides a universal transducer conditioning solution for both high temperature static and dynamic strain gages as well as for sensors in a Wheatstone bridge configuration. Detailed below are specific measurement requirements for gas turbine engine testing and how the challenges associated with these measurements are solved with PFI technology.

Dynamic Strain Measurement:

The measurement of dynamic strain on gas turbines is one of the many challenges facing the measurement engineer. The strain gage is often subjected to very high temperatures and requires high temperature alloys for leads to the sensor. The temperature change after engine startup results in sensor lead resistance changes of ten's or even hundred's of Ohms. On the rotating side of the engine, the leads must pass through a slip ring where there is a high potential for noise coupling. As gages are subjected to the high temperature environment, the substrate can break down and leakage to the test article can occur. Further, the environment of the gage may contain high electrostatic and magnetic fields that couple into the cables.

Measurement of dynamic strain in the environment of a gas turbine engine is not practical with traditional Wheatstone bridge techniques as the variability of lead resistance with temperature results in unacceptable uncertainty of the measurement. In addition, the Wheatstone bridge configuration is unbalanced with respect to noise radiating into the gage leads, which are often unshielded on the rotating side of the engine. The unbalance limits the effectiveness of the differential input stage of the amplifier to reject the noise and results in measurements with poor signal to noise ratio.

Precision Filters developed the balanced constant current technology to allow for wide dynamic range measurement of strain in harsh environments using only a two-wire connection to the gage. The circuit is insensitive to changes in lead resistance with temperature and since the circuit is balanced, the differential input amplifier rejects noise pickup in the leads. An added benefit is that the circuit will continue to measure strain even if a gage terminal shorts to the test article.

In addition to the Precision 28144, balanced constant current technology is available on the 28458 high-density dynamic strain conditioner. For more information on PFI's balanced constant current technology, please refer to the white paper "Balanced Constant Current Excitation for Dynamic Strain Measurements", available for download at www.pfinc.com.

Static Strain Measurement:

Static strain measurements at high temperature are even more difficult. Many of the DC errors removed by AC coupling in the dynamic strain measurement must be understood and properly managed in static strain measurements.

The basic strain gage cannot distinguish between strain imposed by the intended mechanical process and expansion of the test material due to its temperature coefficient of expansion. This reporting of strain due to thermal expansion is often described as apparent strain, or thermal strain. At moderate temperatures (below 250 °C) temperature compensated strain gages are available which minimize reported strain due to thermal expansion. Typically, a three-wire Wheatstone bridge configuration is used to connect the temperature compensated strain gage to the bridge completion inside the signal conditioner.

While the three-wire connection is far superior to a simple two-wire connection, it suffers from three problems. First, variable extension wire resistance caused by varying temperature creates variable gage desensitization and additional measurement uncertainty. Second, even the slightest thermally induced variability in the lead wire resistance can create significant DC output from the bridge if the lead wires are not properly matched. Third, the three-wire Wheatstone bridge connection is electrically unbalanced and has poor rejection of electrostatic noise. While aggressive filtering can remove noise pickup for static only measurements, the three-wire connection disallows simultaneous static and dynamic readings from the same gage in a noisy environment.

The Precision 28144 used in the 4-wire constant current mode will rectify all three of the problems described above. Constant current excitation eliminates uncertainty caused by desensitization and the 4-wire connection eliminates all DC drift problems caused by extension wire resistance. Additionally, the 4-wire constant current connection is electrically balanced and has excellent rejection of electrostatic noise pickup, and therefore it can be used to acquire both dynamic and static strain data from the same gage.

The Precision 28144 Quad-Channel Wideband Transducer Conditioner with Voltage and Current Excitation

High Temperature Static Strain:

At temperatures above 250 °C, apparent strain compensation is achieved by the use of a second compensating gage arranged in a half bridge configuration with the measurement gage. Careful placement of the compensating gage should subject it to the same thermal environment as the measurement gage while avoiding strain caused by the mechanical process. Since the compensating gage exhibits the exact same response to apparent strain as the measurement gage, the apparent strain readings cancel in the half bridge configuration. A 3-wire connection may be used to condition the half bridge, however, this configuration is susceptible to gage factor desensitization and DC errors caused by resistance changes in the extension wires. This problem is compounded by high resistance nickel alloy extension wires, which are commonly used at higher temperatures. To control the desensitization and DC drift errors, a 5-wire connection may be used to correct for excitation losses, which occur in the extension wires.

The Precision 28144 universal conditioner card is fully equipped to handle all of these strain conditioning scenarios, and provide the best possible signal conditioning technique for any static strain requirement.

Wheatstone Bridge Conditioning:

Tests on gas turbine engines often require conditioning of bridge type sensors that require constant voltage excitation. These sensors include silicon diaphragm pressure transducers used to measure dynamic pressures and load cells for measuring engine thrust. In addition, where appropriate, static strain gages may be conditioned in a bridge using completion resistors, if the lead resistance affects are accounted for and are negligible.

The 28144 provides a fully programmable interface for sensors requiring Wheatstone bridge conditioning with constant voltage excitation. Bridge completion may be programmed for 1, 2 or 4-arm gages with precise 120, 350 or 1000 Ohm completion. The 28144 provides programmable shunt calibration to verify the integrity of the bridge as well as measurement system span. Remote excitation sense allows for precise regulation at the sensor. In addition, the Precision 28108 octal bridge conditioner is available for high-density full-bridge conditioning applications.

Tailoring the System Transfer Function to the Measurement:

Care must be taken to select the correct measurement system transfer function as dictated by the test requirements. Tests on gas turbine engines such as engine stalling, bird impact or blade-out require that the measurement system have a well-behaved transient response. The measurement system must not introduce overshoot and ringing in response to transient inputs. Complex time-domain wave shapes, rich in spectral content, must be preserved by the transfer function of the system. For engine order analysis and frequency domain analysis, a flat frequency response is desired and for anti-aliasing, a sharp, selective filter response may be required.

The Precision Filters' FLAT/PULSE filter technology allows the user to set the frequency response characteristics of the signal conditioner under program control. For transient tests or tests where time-domain wave shape preservation is important, program the 28144 to the PULSE mode characteristic. The PULSE mode provides linear phase response, which is required for time-domain wave shape reproduction and outstanding transient response with low overshoot and ringing. For frequency domain analysis, selecting the FLAT filter characteristic will result in outstanding transfer function flatness and a sharp, selective filter response. FLAT/PULSE filter technology is available on all Precision Filters' strain and bridge conditioners.

Elimination of Out-Band Noise:

Some transducers such as piezo-resistive pressure transducers can have very high resonant frequencies that can be excited by transient events and this out-band signal can be larger than the signal of interest. Sources of unwanted low frequency noise can exist such as engine sub-harmonics, triboelectric noise from cable whip or pyro-electric noise from the sensor caused by the large temperature gradients during start-up.

The 28000 amplifier gain is distributed around the filter as "pre-filter" and "post-filter" gain to allow the filter to remove out-band signals such as transducer resonance while still achieving the required full-scale in-band signal level. Using the 28000 "reserve" feature, the user can specify the required protection against out-band noise and the pre- and post-filter gain are automatically distributed to provide this protection. The pre-filter gain is set to achieve the required amplifier headroom for the out-band signals prior to the filter while maximizing dynamic range. After the filter removes the out-band signals, the post-filter gain is set to achieve the desired full-scale output. The 28144 card may be equipped with either a low-pass filter or a high-pass filter cascaded with a low-pass filter to form a band-pass filter. The band-pass configuration and the distributed amplifier gain provides the user ultimate flexibility to eliminate sources of either high-frequency or low-frequency noise.

Accelerometer Conditioning:

As the operating temperature of gas turbines continues to increase, the vibration measurement task becomes more difficult. Accelerometer manufacturers have responded with high temperature accelerometers that perform at temperatures as high as 750 °C and care must be taken when using these sensors. One common characteristic of accelerometers is an extremely low insulation resistance across the piezoelectric sensing element at high temperature. If a general-purpose charge amplifier is used, low frequency gain peaking could be as high as 20 to 30 dB. This will cause excessive low frequency noise, gain errors, and in severe cases total saturation of the charge amplifier. The Precision 28302B is compatible with the highest temperature accelerometers on the market and exhibits less than 2 dB of peaking even with accelerometer shunt resistance as low as 10 KOhm.

Multiple Noise Sources:

Ideally, the charge amplifier gain is set to optimize for the desired in-band portion of the accelerometer signal. Proper span calibration of the instrument assures that a full-scale output will result from a maximum expected in-band vibration signal. Often, the desired vibration signal is buried in undesired noise signals from many sources. Triboelectric noise results from unavoidable cable vibration as the cable is routed on the surface of the vibrating engine. Pyroelectric signal is caused by rapid thermal transients of the accelerometer which normally takes place during test point changes. Electromagnetic and electrostatic coupling is common with power generation or shaker control systems. If analog filters are not used to eliminate these noise signals, then channel gain must be reduced to ensure the composite signal plus noise is within the A/D full scale input range. In extreme cases, this can greatly reduce dynamic range delivered to the A/D converter. The Precision 28302B has sharp high-pass and low-pass filters to separate and remove these noise sources from important vibration measurement signals.

Suppression of Accelerometer Resonance:

Sometimes unexpected high frequency vibration signals correspond with the resonance frequency of the accelerometer. This is often a problem with geared systems or large multi blade systems. Resonance peaking of the un-damped accelerometer could cause more than 20 dB gain to vibration present at these frequencies. In order to prevent saturation of the charge amplifier, it is important to remove these large out-band signals prior to applying any channel gain. The Precision 28302B card has a 3-pole resonance suppression low-pass filter which is located prior to any channel gain. This filter maintains the expected in-band data bandwidth while suppressing the large gain peak caused by the accelerometer resonance.

Velocity and Displacement Outputs:

Often in measurements of rotating machinery, it is desired to record velocity and displacement levels in addition to acceleration. Velocity is computed by integrating acceleration and displacement is computed by integrating velocity. Computation of velocity and displacement can be difficult, especially at low frequencies where the integrators have huge gain. In addition, it is often desired to have a DC output proportional to either acceleration, velocity or displacement to drive a facility alarm, automatic shutdown of the engine or a closed loop control system.

The 28302B offers the convenience of analog velocity and displacement outputs that may be directly recorded by any data acquisition system. The extensive high-pass filtering capability of the 28302B allows the user to remove sources of low-frequency noise that would otherwise saturate the velocity and displacement outputs. The low latency DC output proportional to peak acceleration, velocity or displacement can be monitored for protection of the test article or to drive a feedback control system.

Conditioner Card Selection Guide for Gas Turbine Engine Testing

Card	Type	Channels/ Card	Sensor Type	Excitation	Bandwidth	Gain
28108	Full Bridge Conditioner	8	Strain, pressure, load, low level AC, DC, or Bridge	Balanced Constant Voltage 0-20.475 VDC (30 mA)	100 kHz	x1/4 to x8192
28144	Bridge Conditioner or Dynamic or Static Strain Conditioner	4	Dynamic or static strain, pressure, RTD, load, accels, AC, DC, or any Bridge	Balanced Constant Voltage; Balanced Constant Current	500 kHz	x1/4 to x8192
28302B	SE or Diff Charge, IEPE Accelerometer Conditioner	2	Piezoelectric or IEPE Accelerometer, Remote Charge Converter	Constant Current (IEPE) 8.5 mA	0.3 Hz to 20 kHz	Sensor Sensitivity: 0.1 pC/g to 110 pC/g
28316C	IEPE Accelerometer Conditioner w/LDTEDS	16	IEPE Accels w/LDTEDS, AC filter/amp, Remote Charge Converter	Constant Current (IEPE) 0, 2, 4 or 8 mA	150 kHz	x0.5 to x512
28458	Dynamic Strain Conditioner w/AC Input Coupling	8	Dynamic strain w/2-wires, AC filter/amp	Balanced Differential Constant Current 0, 5, 10, 15, 20 mA	190 kHz	x½ to x1024
28324	SE Charge, IEPE Accelerometer Conditioner	4	Piezoelectric or IEPE Accelerometer, Remote Charge Converter	0–20 mA	190 kHz	x½ to x1024

Verification of Cables and Sensor Health:

At Precision Filters, we know that even the best signal conditioner is of little value if the sensor or input wiring is faulty. Having worked closely with our end users on many difficult tests, we know the harsh environment of testing on gas turbine engines takes its toll on sensors, cables and connectors. Discovering a failed sensor or cable after the test is too late and can result in lost data that can never be recovered. Quick and easy visibility of cable and sensor health can allow timely corrective actions that can save crucial data.

We have built test hardware and software into our 28000 Signal Conditioning System that allows the system user to easily run a series of automated sensor and cable health checks. Below are some of the verification capabilities built into our suite of signal conditioners for rotating machinery.

Strain Gage Loop Resistance Measurement:

Dynamic strain measurements often require complicated wiring schemes. Long cable runs, multiple connection points, high-temperature high-impedance very small diameter wire and slip rings combine to cause uncertainty in the strain gage connection. Often a sudden increase in gage resistance is a predictor of gage failure.

The Precision 28144 gives continual real time monitoring of the total "Loop Resistance" of the gage and cable circuit. This loop resistance reading can be compared to preset limits to alert the user of unexpected resistance shifts as well as gross gage short and gage open conditions. Pre- and post-test loop resistance measurements can be presented as a report for quality assurance (QA) and as test validity documentation.

Cable Roll-off:

One often asked question of many measurements engineers is "How will my cable capacitance affect my high frequency strain measurement?" This question can be answered quickly and easily and all from the convenience of the control room. The AC dither current feature of the 28144 and 28458 modulates a small AC current on top of the DC excitation current to stimulate an AC signal across the actual strain gage sensing element. Since the stimulus signal is based at the sensor, it will exhibit the same roll-off characteristics as a signal resulting from actual dynamic strain. The test frequency of the dither signal can be increased as necessary to chart the cable roll-off characteristics and validate the cable circuit for use at the desired measurement frequencies.

Insulation Leakage Measurements:

In extremely hot sections of a gas turbine engine, it is impossible to use standard insulating materials in gage wiring. Often a rigid section of a stainless steel or Inconel sheath encloses high temperature inner conductor wires. The inner core of the sheath is filled with magnesium oxide (MGO) as a high temperature insulating material. The insulating properties of the MGO are affected by moisture absorption at damage points or improperly sealed cable terminations. In extreme conditions, insulation breakdown can cause a leakage path to ground and corrupt a gage reading. Other causes of cable leakage are fatigue or failure at extension wire tie down points, or in the strain gage itself.

The leakage detection feature of the 28144 continually monitors leakage and compares readings to preset threshold limits. Sensors which show higher than normal leakage can be quickly identified prior to or during the test run.

Conditioner Card Selection Guide for Gas Turbine Engine Testing

Card	Filter Poles	Filter Types	Fc Range	Comments:
28108	4-pole	Flat/Pulse LP	Flat Mode: 100 Hz to 25.5 kHz Pulse Mode: 50 Hz to 12.75 kHz, Programmable	Most cost effective conditioner for full bridges
28144	4 or 8-pole	Flat/Pulse LP, Band-Pass	Flat Mode: 2 Hz to 204.6 kHz Pulse Mode: 1 Hz to 102.3 kHz, Programmable	Full featured conditioner when test requirements change between static or dynamic strain and 1, 2 or 4-arm bridge
28302B	HP: 12-pole LP: 6-pole	LP, HP, Band-Pass	HP 5 Hz to 1,275 Hz, Programmable LP 50 Hz to 12,750 Hz Programmable	Use for accelerometer, velocity or displacement measurements in harsh environments of gas turbine engines
28316C	4-pole	BU, TD	100 Hz to 30 kHz, Programmable.	Most cost effective conditioner for IEPE accelerometer and AC filter/amplifier
28458	4-pole	Flat/Pulse LP	FX02: 300 Hz, 1 kHz, 3 kHz,.10 kHz & 30 kHz FX03: 10 kHz, 20 kHz, 40 kHz, 80 kHz & 100 kHz	Most cost effective conditioner for dynamic strain measurements
28324	4-pole	Flat/Pulse LP	FX02: 300 Hz, 1 kHz, 3 kHz, 10 kHz & 30 kHz FX03: 10 kHz, 20 kHz, 40 kHz, 80 kHz & 100 kHz	Most cost effective single-ended charge and accelerometer conditioner

IEPE Sensor Health:

For low temperature vibration measurements (below 250 °C) IEPE type accelerometers can be used. A common measure of IEPE sensor health has always been the bias level. Traditionally a front panel analog VU meter gave visual indication of bias level for each channel. The physical size and analog nature of the VU meter has caused it to disappear in modern computer controlled instruments. The 28000 IEPE conditioners not only provide continual real-time monitoring of IEPE bias levels, but also allow the user to enter upper and lower comparison limits to detect a sudden shift in bias.

A second predictor of IEPE sensor failure is a sudden shift of output resistance, Z-out, of the FET transistor at the sensor output. The 28000 IEPE conditioner "Z-out" feature has the ability to measure the output resistance of all attached sensors. By comparing Z-out readings to pre-programmed baseline readings, a shift in Z-out can be detected. Both Z-out and bias level can be presented as a report to be included in test quality or validity documentation.

T Insertion:

Acceleration measurements at high temperature (above 250 °C) require the use of piezoelectric (charge mode) accelerometers. A very crude check of accelerometer functionality is known as the "tap test". One by one each accelerometer case is physically tapped or stimulated with a hand held shaker. A second operator in the control room monitors the output display, verifies receipt of the signal and attempts to make some inference on functionality of the installed accelerometer. While this is a crude and time consuming technique, it is important in harsh environments to confirm basic sensor and cable health.

The Precision Filters 28324 accelerometer conditioner has built in "T-Insertion" capability to electronically stimulate the attached piezoelectric accelerometer to output a charge signal. Charge output of a stimulated accelerometer is dependent on the exact properties of the accelerometer and connecting cable. This output is extremely repeatable and can therefore be used to detect any change resulting from a faulty or damaged accelerometer. Additionally the stimulation frequency can be increased to interrogate the accelerometer in the vicinity of its mounted resonance frequency. Since resonance characteristics are affected by accelerometer mounting, high frequency performance can identify mechanical damage that occurred during a test run.

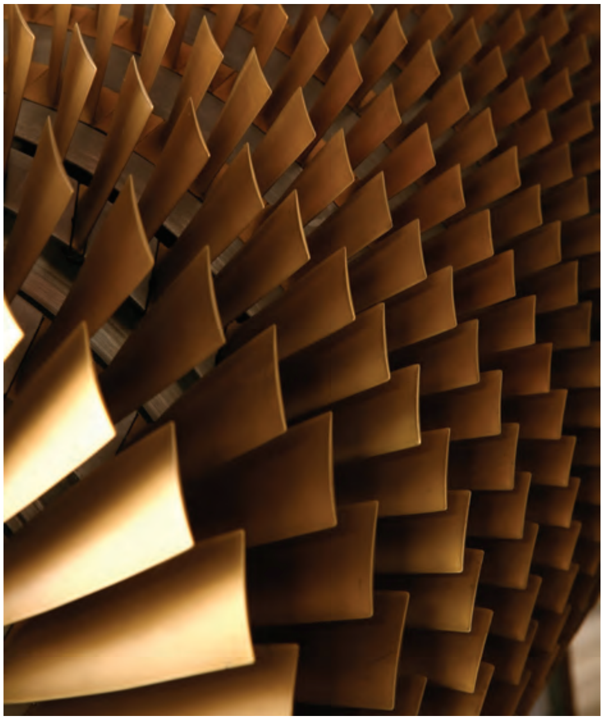
In summary, T-Insertion can be used as an "Electronic Tap-Test" to gather information on all accelerometer channels quickly and easily from the convenience of the control room. Again, pre- and post-T-Insert measurements can also be presented as a report that can greatly enhance QA documentation and add a new level of test validity documentation.

Muting Faulty Sensors:

While most attention is paid to properly functioning sensors, a "real world" perspective forces us to consider sensors that are NOT functioning properly. Often a malfunctioning sensor can cause noise or fault currents that can corrupt other properly functioning channels. One common example of this phenomenon is "gage chatter" caused by strain gages with intermittent connections.

Due to the extremely harsh environment of strain gages on gas turbine engines, it is not uncommon for a gage to eventually fatigue and fracture, creating an open circuit condition. When the gage loop is open circuited, the connecting wires suddenly drift to the power supply rails of the signal conditioner. A gross fault in a strain gage resulting in a permanent open condition does not cause a noise problem; however, an intermittent gage will create a gage chatter condition whereby the connecting wires continually switch between the high voltage fault level and the proper low voltage operational level. This chatter condition creates a hostile noise source to any other gage extension wires in the vicinity of the hostile cable. This problem is exacerbated at the rotating side of a slip ring where the extension wires may not be optimally shielded. Often a user may try disabling the noisy signal conditioner output signal. While this will indeed quiet the failed channel, the unsuspecting user will still be in a quandary as to why other channels are showing increased noise.

Depending on the sensor type, various techniques must be used to quiet the channel's input and output circuits and ensure that no noise coupling occurs. Precision 28000 signal conditioning channels have a "MUTE" feature, which places the channel in its quietest quiescent state and minimizes the possibility of coupling noise to properly functioning channels.



System Self Test and Calibration:

Since the signal conditioner is a key component in the critical path of important test data, performance specifications must be rigorously proven and documented. Yearly calibration is only the minimum requisite for defendable test data. Continual setup, tear down and reconfiguring of sensitive test equipment demands a rigorous test protocol that demonstrates that every channel was working properly at the time of the actual test. At Precision Filters, we know that a verification test is seldom run if the difficulty of running the test outweighs the perceived advantage. The Precision 28000 self-test subsystem can conduct rigorous yearly calibrations as well as quick go/no-go tests all at the push of a button, and all without removing the system from the equipment rack.

Yearly Calibration:

All test and measurement systems require periodic calibration. Typically, this means that test systems are dismantled, cards uninstalled and shipped either to an in-house cal lab or back to the manufacturer.

Precision Filters' built-in test hardware and software allows the user to perform NIST traceable calibration tests on-site without removing the system from the equipment rack. Traceability is afforded by the use of an Agilent 34410A high performance digital multi-meter (DMM) kept in calibration by a third party metrology test lab. Test software residing in the 28000 Graphical User Interface (GUI) first verifies calibration and traceability information of the DMM before proceeding step by step into a extensive test routine designed specifically for each card type. Every card function is exercised and all data-critical performance characteristics are accurately measured and compared to published specifications. These calibration tests are the same rigorous measurement routines that are performed in the factory prior to shipment and serve as a excellent Factory Acceptance Test (FAT) to be used by a customer upon receipt of new equipment. Performance characteristics measured by the 28000 FAT are shown below.

- Filter Frequency Response
- Channel to Channel Phase and Amplitude Match
- Gain Accuracy
- Offset Voltage
- AC/DC Coupling
- Max Level
- Noise
- CMRR
- Overload Detectors
- Amplifier Stage (Wide-Band) Frequency Response
- Excitation
- Auto Balance
- Shunt Calibration

Go/No-Go Tests:

While yearly calibration shows basic compliance to quality standards, it does little to reveal a problem that may have developed between tests. Finding a bad channel in a yearly calibration can be too late especially if that channel was potentially used on many tests throughout the year. The most rigorous test protocols require additional tests be run before and sometimes after every test.

In order to keep these tests viable within the time constraints of actual testing, they must be crafted to be quick and easy and minimize delays of actual engine testing.

The 28000 suite of Go/No-Go tests were designed with speed and simplicity in mind. While the FAT verifies all channel parameters, the Go/No-Go quickly verifies only the present run-time settings of each channel. Gain, filter setting, DC offset and excitation levels are quickly measured and verified and presented in report form. The Go/No-Go report is an excellent addition to a quality assurance report and proves beyond any doubt that the equipment was functioning properly.

Life Cycle Costs:

The life cycle costs of a system are the total cost of owning, operating and maintaining the system over the period of service. Included in the life cycle cost is the purchase cost, the installation cost, the acceptance testing cost, the operating cost and the cost of on-going maintenance and calibration. Also included and over looked is the cost of acquiring bad data. While the up front purchase price is significant, the cost of operation and maintenance of the system over its lifetime will usually far exceed the purchase cost. The cost of bad data, even for one test on a gas turbine engine, can exceed the purchase price of the system many times over.

The 28000 System significantly reduces the operation and maintenance costs and provides tools to aid the user in validating the test data to reduce or eliminate the chance of bad data. The computer-controlled setup of the 28000 System speeds test setup time. Sensors and cables are verified using the 28000 System built-in transducer health monitoring. Since sensor and cable health is monitored and reported on the fly during the test run, timely corrective action can be taken to potentially save critical data. Channels with faulty sensors can be MUTED and data from these channels tagged as "suspect".

The programmed settings of the 28000 System are directly measured and verified via the automated Go/No-Go tests. Go/No-Go checks can be run before and after each test run to verify the integrity of the system. The built-in Factory Acceptance Tests (FAT) allows the user to calibrate the system on-site in the equipment rack, reducing the expense of off-site calibration and system down-time.

Using the capabilities of the 28000 System, the user can perform system and sensor verification rapidly. For example, sensor loop resistances can be collected in a matter of seconds in contrast to tedious manual measurements which can take several hours for large channel count systems. Full reports are stored on the host and may be presented as proof of test data validity.

Table 1 outlines the difference between the typical methods and 28000 System Methods of performing verification testing and system calibration.

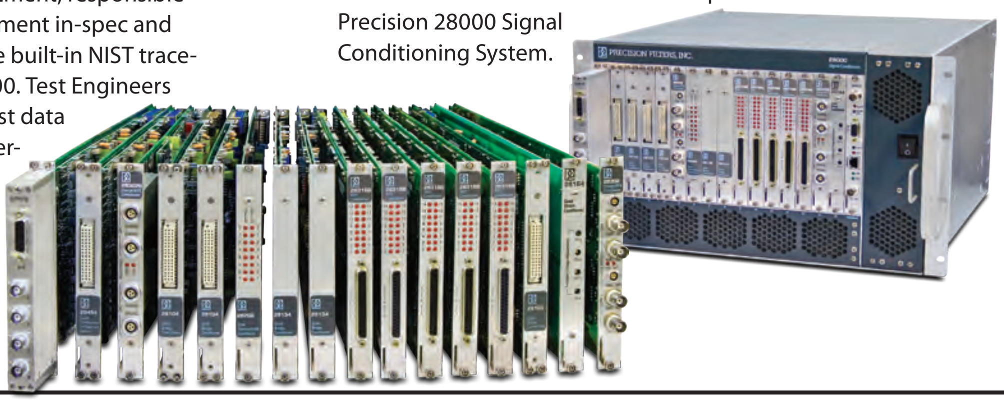
Table 1: Comparison of verification and calibration testing costs for 128-channel signal conditioning system

Activity	Frequency	Typical Method	Yearly Hours	28000 System Method	Yearly Hours
System Calibration	Once per year	Tear system down and ship to offsite calibration facility. System downtime: 30 days. Calibration cost includes verification of critical specs and realignment of offset and gain potentiometers while manually monitoring internal circuit points.	240 hr	Run calibration in-situ using Precision Test Subsystem, running unattended over weekend. Realignment performed automatically using precision digital potentiometer adjustments. Total time: 2 hours technician time.	2 hr
Amplifier Setup	Once per test (52 times per year)	Manually set each channel gain, excitation, sensor configuration via knobs/dials at front of unit. Setup of 128 channels takes 1 min/channel. (2 hours total time)	2 hr x 52 = 104 hr	Program channels in group mode. Store and recall setups for quick and easy system configuration. Setup accomplished in minutes.	0.2 hr x 52 = 10.4 hr
End-to-end verification of system	Before and after each test. (104 times per year)	Technician manually inserts special calibration box (channel-by-channel) across the strain gage. Measure channel output and manually adjust gain as necessary. Verify channel bandwidth. Verification time 2 minutes/channel (4 hours for 128-channel system).	4 hr x 104 = 416 hr	Fully automated via Precision AC Dither Current Test Mode. End-to-end verification time for span and system bandwidth is <10 minutes. Precise 28000 vernier gain means no manual gain adjustments are necessary.	0.1 hr x 104 = 10.4 hr
Measure transducer loop resistance and resistance to ground.	Before and after each test. Preferably during test. (104 times per year)	Disconnect input cable from amplifier (channel-by-channel). Measure loop resistance with hand held DMM. Record readings and transfer to spreadsheet. Verification time 2 minutes/channel (4 hours for 128-channel system).	4 hr x 104 = 416 hr	Fully automated via Precision loop resistance Go/No-Go test logs loop resistance readings to file. Verification time is <10 minutes.	0.1 hr x 104 = 10.4 hr
Measure Excitation	Before and after each test (104 times per year)	Monitor excitation via amplifier test points with DMM. Verification time is 1 min/channel (2 hours for 128-channel system.)	2 hr x 104 = 208 hr	Fully automated via Precision excitation Go/No-Go test. Verification time is <10 minutes.	0.1 hr x 104 = 10.4 hr
Bridge Balance	Once per day (150 days testing per year)	Monitor bridge output via front panel test points at amplifier input. Adjust front panel potentiometer with screwdriver to achieve balance. Time to balance 128 channels: 1 min/channel (2 hr per system.)	2 hr x 150 = 300 hr	Push button automatic bridge balance. Balance 128 channels in <1 minute.	0.1 hr x 150 = 15 hr
Measure System Noise	Before and after each test (104 times per year)	Disconnect input cables. Replace with shorting cable. Measure and record noise at channel output with connected data acquisition system. Time to measure system noise with shorted input: 1 min/channel (2 hr per verification of 128-channel system).	2 hr x 104 = 208 hr	Precision Test mode SHORT allows user to disconnect from sensor and short the amplifier input under program control.	0.1 hr x 104 = 10.4 hr
Total Yearly Hours			1,892 hours		69 hours

Table 1: Assumptions: System runs 52 tests per year

Conclusion:

When a "systems approach" is used in the design of a signal conditioning system, it appeals to all members of the measurements team. The metrology department, responsible for maintaining high quality test equipment in-spec and traceable year after year, appreciate the built-in NIST traceable calibration capabilities of the 28000. Test Engineers routinely challenged to defend their test data appreciate the automated reports generated by the 28000 sensor and cable health and signal conditioner Go/No-Go tests. Data Analysts appreciate the quality, highly accurate and validated output data. And finally, Project Engineers responsible for staying on budget and always concerned with the yearly "bottom line" appreciate the low life cycle cost and low overall cost of ownership of the Precision 28000 Signal Conditioning System.



PRECISION FILTERS, INC.
Transducer Conditioning Systems ■ Filter/Amplifier Systems ■ Signal Switching Systems

Precision Filters, Inc.
240 Cherry Street
Ithaca, New York 14850

Telephone: **607-277-3550**
E-mail: **pfinfo@pfinc.com**
Web Site: **www.pfinc.com**

P8462 Rev. -