

Nontraditional Uses of ICP™ ‘Power’ New Sensors

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Modern dynamic signal analyzers (DSAs) provide ICP® sensor power as the *de-facto* standard for dynamic sensor signal conditioning. From the humble beginnings of single- and dual-channel analyzers of the late 1960s and early '70s, modern analyzers serving the sound and vibration market have matured into PC-based, modular structures typically providing multiples of 4, 8, or 16 channels. With the cost savings in the ADC (analog to digital converter) realized from the consumer audio boom and the competitiveness in DSA pricing, even entry level systems often start with channel counts of 16, 24 or higher. The liberal channel counts of these modern analyzers result in available ‘space’ for additional sensors such as microphones, strain gages and tachometers. These additional sensor inputs allow for ‘hybrid’ measurements and analyses or order tracking of complex, rotating systems with the possibility of resolving closely spaced orders.

History. Dubbed as a “smart sensor” of the day, the ICP system was introduced as a new way to power piezoelectric pressure, force and acceleration transducers with built-in signal conditioning in the late '60s. This new method utilized a field-effect transistor (FET) within the sensor for impedance conversion at the crystal, striking a balance in performance, simplicity, and cost. It met the needs of a broad range of vibration measurement applications and, as a result, users appreciated the simplified, reliable operation. This opened up new markets in machine condition-based maintenance and manufacturing process monitoring. As years passed, additional developments in internal piezoelectric sensor FETs have accommodated higher temperature and lower noise operations. There are very few measurement applications today that still require an external amplifier for a traditional charge sensor.

The simplified, two-wire ICP sensor signal conditioning has become so popular that it is now standard in virtually every modern DSA. Typical analyzers have a selectable input stage, which can be toggled between ‘ICP’ and ‘voltage’ to accommodate almost any generic sensing input. During the 1980s, the availability of ICP sensor power on large modal test systems in part led to the development of low cost accelerometer arrays for large-channel automotive and aerospace test applications. These lower cost accelerometers likewise increased ‘typical’ DSA system channel counts. By the 1990s, the vast majority of piezoelectric sensor mea-

surements used ICP power as the primary means of signal conditioning. Into the 21st century, ICP sensors led the way for the latest generation of “smart sensors” utilizing transducer electronic data sheet (TEDS) technology by adding digital memory to the analog sensor as shown in Figure 1.¹

Implementing the voltage mode operation of ICP sensor signal conditioning simply requires an excitation voltage (normally +18 to 27 V) supplied across a constant-current diode (typically 4 to 20 mA) fed through a blocking capacitor coupled to a resistive ground link. The latter components form an RC circuit that is a single-order, high-pass filter for removing the DC bias voltage present on the internal sensor FET. Functionally, the RC component values define the useful low frequency response of the sensing channel. This simplicity in design implementation helped propel DSA vendors of the early days to support ICP sensor signal conditioning over other variations of low-impedance operation.

Once ICP sensor signal conditioning became ubiquitous, users became attracted to sensors that would operate from the same power and eliminate a stand-alone signal conditioner. Typically, the stand-alone conditioners would be provided with selectable features (such as various gain settings and filters) but a large portion of users found that, for most applications, a single setting would be chosen and maintained. Selectability aside, the performance compromises of ICP systems are negligible for most automotive and general-purpose applications.

Acoustics. Over the past decade or so, sound and vibration test professionals, particularly those in the automotive NVH and aerospace markets, have developed measurement applications that use more and more microphone channels. Given the increasing availability of dynamic measurement channels, the first “new-generation,” ICP-powered sensors were created. Driven by such large, multichannel applications as near-field acoustic holography (NAH), temporal array and inverse frequency response function techniques,² measurement systems utilizing dozens if not hundreds of microphones have become more common.

Traditional acoustic measurements are made with a condenser microphone, preamplifier and power module. The power module supplies 200 volts to polarize the microphone sensor, essentially an air capacitor. Traditional microphone preamplifiers use a seven-wire scheme to



Figure 1. ICP accelerometer cut-away, annular shear design with TEDS technology.

support supply voltage/ground and polarization voltage/ground, among other needs. Conversely, an ICP acoustic measurement couples a prepolarized condenser microphone with a new preamplifier designed to be powered from a standard ICP constant current excitation source in a two-wire scheme. The prepolarized microphone forms a perfect complement to ICP operation, since it doesn't require a 200 V polarization source (see Figure 2). When mated with a prepolarized microphone, an ICP-powered preamplifier provides conditioning of the high-impedance microphone signal with negligible performance compromises. Given commercially available 1/2 in. and 1/4 in. microphones coupled with ICP preamplifiers, acoustic measurements can be made at levels ranging from near 15 dB to upwards of 166 dB. This obviously covers the vast majority of acoustic measurement applications.

Cost savings achieved by eliminating traditional microphone power modules are analogous to savings achieved by switching from a charge to an ICP accelerometer, saving hundreds or even thousands of dollars per channel. Not only is the cost of a microphone power module eliminated, but also the seven-pin LEMO cabling is replaced by lower-cost BNC coaxial cabling. As a result, there was and continues to be a very large migration from traditional microphone measurement channels to the new generation of ICP preamplifiers for precision pre-polarized microphones.

Rotating Machinery. Another instrument common to many sound and vibration test labs is the tachometer. The need for a reference to rotating component orders is common when considering operationally induced dynamic inputs. Traditionally, this meant test engineers would need some form of rotational pickup (for example optical, laser, magnetic, etc.) along with an additional signal conditioning box, auxiliary power and multi-wire cabling. The LaserTach™ shown in Figure 3 is a new tachometer pickup that couples a Class IIIA (laser-pointer safe) laser emitter with a photo detector, in a single package that is powered by ICP-sensor signal conditioning. It offers all of

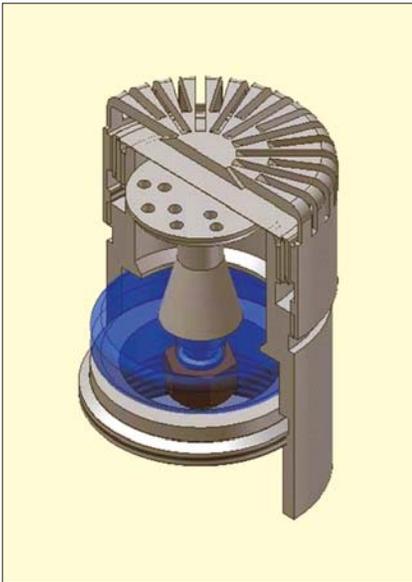


Figure 2. Prepolarized condenser microphone cut-away shows protective grid, diaphragm and backplate.

the advantages of a laser (excellent operating distance, visible indicator, etc.). With its BNC output connector, the LaserTach connects to a measurement system using standard, low-cost coaxial cabling just like any other ICP accelerometer or microphone channel. This greatly simplifies test system configuration and facilitates the use of many tachometer sensors into a multichannel DSA, important when analyzing complicated mechanical systems with multiple rotating components.

The LaserTach is an ICP sensor that requires at least 3 mA of constant current and digitally samples the photo detector at 1800 Hz. The uncertainty associated with this sampling is uniformly distributed from the mean or true value so, that when processed with FFT averaging, the uncertainty will converge to 225 μ sec. By pointing at retroreflective tape on the rotating shaft, the LaserTach's photo detector responds to the reflected laser light off the tape. The resulting output of the LaserTach is an analog voltage pulse train illustrated in Figure 4 that drops approximately 1 volt with detection of the laser light.

Adapting to ICP power has been the key for large-scale, multiple-order referencing operations on rotating sources. In fact, new techniques like the time-variant discrete-Fourier transform (TVDF) method of order tracking³ are providing analysis techniques that take sampled rotating reference data and resolve orders as small as 1/100 of an order. The evolution in multiple rotating reference and analysis techniques is similar to modal analysis techniques as the state of the art progressed from SIMO (single input/mul-



Figure 3. ICP LaserTach tachometer pickup.

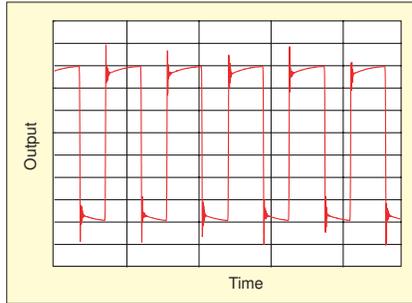


Figure 4. Typical LaserTach pulse train output of once-per-revolution retroreflective tape marker.

tipple output) to MIMO (multiple input/multiple output) measurements.

Strain. Force and strain measurements have long been used in test laboratories to monitor and control various manufacturing operations. Traditional foil strain gages provide static and low-frequency strain data but also require cumbersome bonding techniques, four-wire operation, and bridge supplies. Additionally, low gage factors often result in poor signal-to-noise ratios and necessitate modification (necking) of the test structure to enhance and amplify the strain in the area to be measured.

Recently, a new dynamic strain gage has been introduced utilizing a piezoelectric strain sensing element and low-impedance ICP operation. Measuring the basic strain sensitivity of a piezoelectric crystal, the units employ beam-type elements bonded directly to the base of a protective package. The sensor houses the crystal and the internal FET for low-impedance ICP operation. ICP dynamic strain gages are reusable, simple to mount/fixture, and require no added structural preparation or modification, since they are typically over 100 times more sensitive than traditional foil strain gages. This new class of strain gage has proven extremely effective in a variety of applications ranging from snowboard testing⁴ shown in Figure 5, noise path analysis in automobiles⁵ and press force monitoring on structures like riveting machines for ladders.



Figure 5. PCB 740B02 ICP dynamic strain sensor, shown with snowboard measurement application.

Conclusion. Each year hundreds of thousands of ICP sensors are sold. The aggregate growth of the ICP market has compounded by more than 10% every year for the last 30 years, and as a result, dynamic signal analyzer vendors have adopted ICP as the *de facto* standard. Operating over inexpensive, two-wire cable, the low-impedance operation and resulting noise immunity excels in environments where low signal levels and long cable runs are common. This is most evident in the field of modal analysis, which helped to develop dynamic-array accelerometers and microphones. Improving the usability of acoustic and rotational sensors is just as beneficial as the improvements in vibration sensors. As users continue to enjoy ICP operation and adopt more ICP sensor types, vendors and customers are rewarded by simplifying measurements so that dynamic sensors can be used to improve the performance of products and processes.

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