Gerstner Laboratory
for Intelligent Decision Making and Control
Czech Technical University in Prague

Series of Research Reports

Report No:
GL 128/01

PC-Based Data Acquisition Systems

Petr Kadaník

kadanik@feld.cvut.cz

http://cyber.felk.cvut.cz/gerstner/reports/GL128.pdf

Gerstner Laboratory, Department of Cybernetics
Faculty of Electrical Engineering, Czech Technical University
Technická 2, 166 27 Prague 6, Czech Republic
tel. (+420-2) 2435 7421, fax: (+420-2) 2492 3677
http://cyber.felk.cvut.cz/gerstner

Prague, 2001

ISSN 1213-3000

PC-based Data Acquisition Systems

An Overview of the DAQ structure and terminology for the AC motor diagnostic purposes

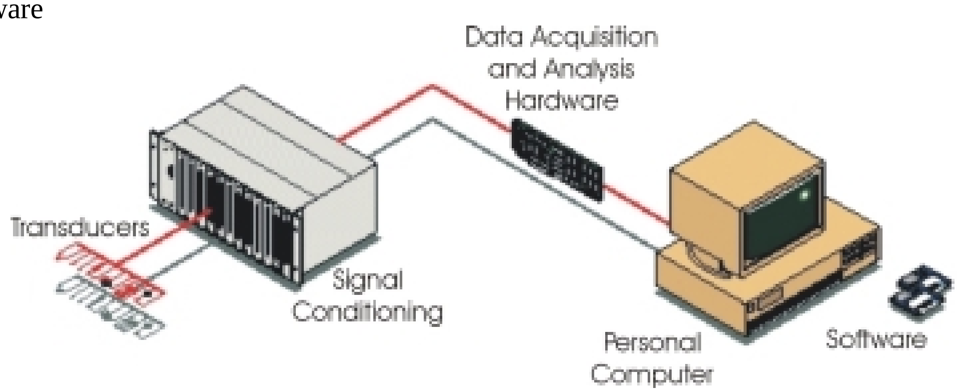
Created by Petr Kadaník
Prague, February 2001

Contents

Introduction

Today, most scientists and engineers are using PC-based data acquisition (DAQ) systems in laboratory research, test and measurement, and industrial automation.
Typically, DAQ plug-in boards are general-purpose data acquisition instruments that are well suited for measuring voltage signals. However, many real-world sensors and transducers output signals that must be conditioned before a DAQ board or device can effectively and accurately acquire the signal. This front-end preprocessing, which is generally referred to as signal conditioning, includes functions such as signal amplification, filtering, electrical isolation, and multiplexing. In addition, many transducers require excitation currents or voltages, bridge completion, linearization, or high amplification for proper and accurate operation. Therefore, most PC-based DAQ systems include some form of signal conditioning in addition to the plug-in DAQ board and personal computer.
Obtaining proper results from a PC-based DAQ system depends on each of the following system elements:

- Transducers
- Signal conditioning
- DAQ hardware
- The personal computer
- Software



Transducers

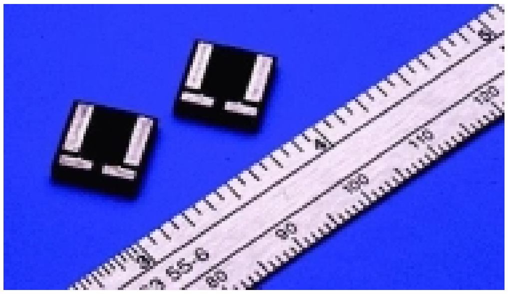
Transducers are devices that convert one type of physical phenomenon, such as temperature, strain, pressure, or light, into another. The most common transducers convert physical quantities to electrical quantities, such as voltage or resistance. Transducer characteristics define many of the signal conditioning requirements of a DAQ system.

Current Sensors

Deciding which current sensor to use can be a formidable task because there are at least 10 well established methods for measuring current. Fortunately, when the designer is armed with a general understanding of the various methods, the once daunting task becomes simply a matter of matching the sensor application's requirements with the appropriate sensor technology.

Sense Resistors

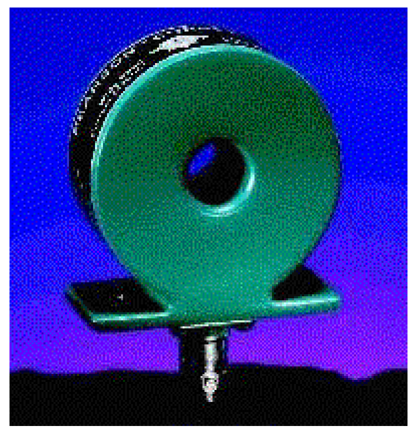
One of the oldest and most reliable methods of sensing current is with a resistor. This approach is noted for its low cost, good precision and ease of use. Sense resistors are by far the most popular current sensor choice for low cost, low current applications, such as power supplies and motor drives. However, two important limitations are their inherent lack of isolation and large insertion loss at high currents.
Sense resistors measure current based on Ohm's Law; the simple linear relation between a current and a voltage across the sense resistor. Unfortunately, this ideal relationship is degraded by the influences of time,



frequency, the environment and, most important, temperature. Temperature errors may come from external sources or from self heating losses. To maintain accuracy over these conditions, high quality resistor designs must pay special attention to electrical layout (parasitics), the choice of resistance materials, and thermal management.
All resistive sensors are limited in bandwidth by the effects of parasitic inductance and capacitance. Inductive reactance dominates most designs, especially in low-ohmic resistors. The error increases with increasing frequency and decreasing resistance. The high inductance of conventional wirewound resistors makes them unsuitable for precision AC current sensing. Capacitance reactance is most important when using a foil resistor on conductive substrate. Manufacturers typically publish layout suggestions, reactance curves and equivalent circuit models as part of the product specification.

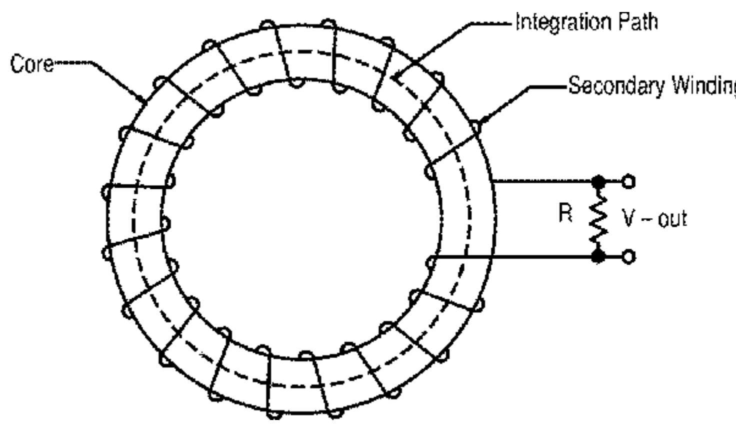
Current Transformers

Current transformers are simple AC devices, usually completely passive, making them the only common technology that combines low insertion loss and isolation without the need for active circuitry. In general, current transformers come in two main classifications: inexpensive, lower frequency devices intended for constant frequency (60 or 400 Hz) power industry transducers, and fixed-ratio, instrumentation grade devices often called current monitors.
Current monitors have a built-in, factory calibrated termination that permits easy connection to standard voltage-measuring test equipment and are shielded from stray magnetic fields. The internal termination, consisting of distributed resistances, greatly increases the transducers linearity over frequency by controlling the parasitic effects of inductance and capacitance.



General purpose current monitors offer bandwidths from 1Hz to 20MHz and linearity and accuracy of 0.1% and 0.5%, respectively. Special units have bandwidths >200MHz.

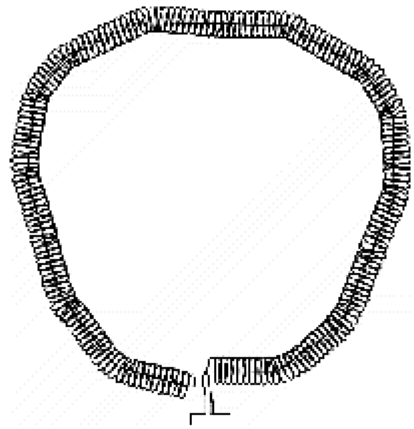
The simplified transformer has a toroidal, high permeability core wound with a coil of “n” evenly distributed turns and terminated in a resistance, R. The primary circuit, not shown, consists of a long wire, or path of current flow, along the axis of the toroid.



Rogowski Coils

Rogowski coils, also called air-cored coils, have been in limited use as AC sensors since 1912 but have recently become popular due to advances in integrator design. Advantages include: output isolation, large measurement range, high bandwidth (to 1.5MHz), good accuracy (<2%) and good linearity (<0.5%).
The absence of an iron core virtually eliminates circuit loading and saturation concerns and contributes to an almost unlimited overcurrent tolerance. Modern Rogowski coils have an extremely wide measurement range – from 30A to more than 100kA full scale, with sensitivities ranging from 0.01mV/A to 100mV/A.

Rogowski coil theory is based upon Faraday's Law that states, "The total electromotive force induced in a closed circuit is proportional to the time rate of change of the total magnetic flux linking the circuit." The coil provides a voltage output proportional to the time rate of change of the magnetic field produced by the primary current. Through the use of an active electronic integrator, the relationship simplifies to an output voltage equal to the input current multiplied by a gain constant.



A simple flexible Rogowski coil is bent into a closed path to completely capture the flux passing through its aperture. The wire loop may be configured as a single turn, a simple helix, a toroid, or other configuration used to form a sensor. One characteristic of this configuration is the coaxial routing of the coil end back to the beginning.

This allows the coil ends to be temporarily separated to allow installation around a primary conductor. If this coaxial return was not incorporated the sensor would essentially become a one-turn loop around the conductor and would be sensitive to any magnetic field that was perpendicular to the plane of the sensor.

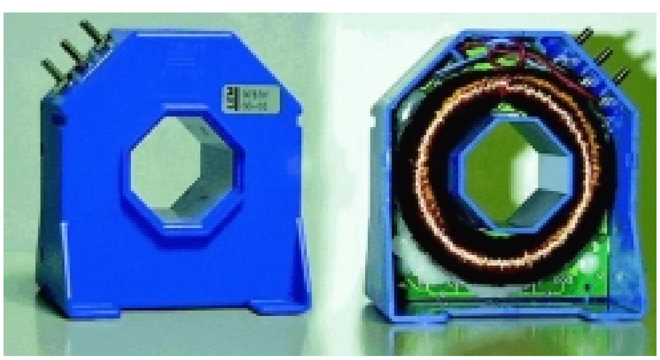
The maximum current range is affected by both the frequency and magnitude of the measured current. This limitation exists due to the nature of the technology, and the finite gain-bandwidth and output swing of the integrator electronics. Most probes provide a di/dt capability from 250 A/sec to 250 A/µsec. Variables such as number of windings, cross sectional area, amplifier gain, zero drift and, in particular, shielding, affect di/dt. The lower limit of di/dt is determined by the integrator design.

Accurate measurement is dependent on a uniform coil cross section. Bending flexible coils into a closed path deforms the circular cross section into an oval, decreasing the turns area. Exceeding the minimum bend radius of the flexible form can cause some turns to permanently shift or even break.

The interruption in turns at the ends of the coil or "gap" can also cause non-uniformities that contribute to position sensitivity errors. This can occur where there are large gradients in the fields impinging on different parts of the sensor, such as measuring current on a small conductor relative to the measurement head. Additional windings near the probe gap reduce this problem.

Hall Effect Current Sensors

Hall Effect sensors are among the most popular solutions for AC and DC measurements requiring an isolated output. These current sensors use several building blocks: the magnetic core, Hall element, Hall element bias source and output amplifier.

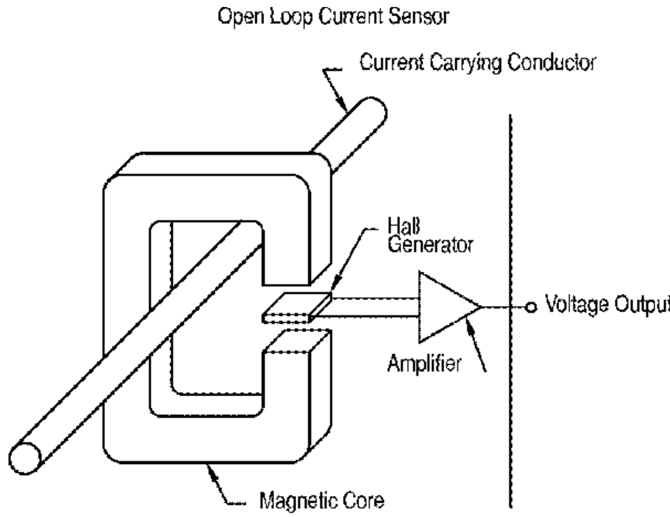


A current-carrying conductor placed in the core's aperture produces a magnetic field proportional to the conductor current. The core concentrates the magnetic field, whose flux excites the Hall element mounted in the air gap. The amplified Hall generator output voltage is proportional to the flux.

Open-Loop Hall Current Sensors

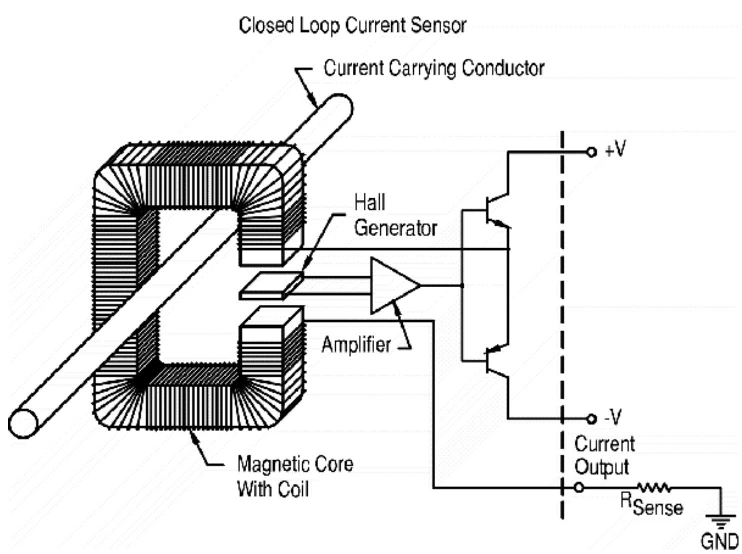
In open-loop designs, the low level signal is amplified and used directly as the output of the sensor. Because linearity and drift are limited by the components, they must be selected for good temperature stability and saturation characteristics.

Open-loop Hall technology, with its low power voltage output, consumes the same power regardless of the aperture current. This along with its low cost, low weight and excellent performance with respect to price make it the preferred type for battery operated applications. These Hall elements are frequently packaged as a discrete part, opening up its application in custom circuits such as internal current and flux sensors in motors and other devices.



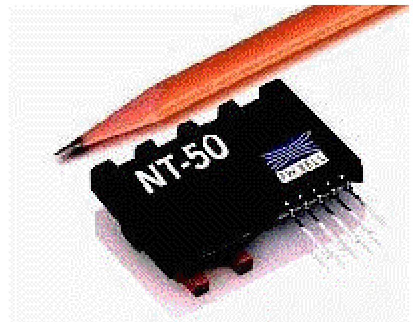
Closed-Loop Hall Current Sensors

Closed-loop Hall sensors use feedback to improve performance. The circuit concept is analogous to that of the operational amplifier. Rather than forcing a zero voltage at the summing junction, this device forces a zero magnetic flux.
The summing junction consists of a high-permeability core, the primary conductor and a secondary, or compensation coil, wound in series opposition around the core. The current transfer ratio is established by balancing the Ampere-turns on the core. Thus, for 1000:1 ratio and a single-pass primary, the secondary will have 1000 turns.
The Hall element functions as the input error amplifier and is optimized for sensitivity. Together with a high gain, high current output amplifier, the circuit produces a compensation coil current that nulls the magnetic circuit and closes the magnetic loop. This current may then be used directly as a current output, or with an output sense resistor.
The measuring resistor is inserted between the measuring terminal and the power supply common for either of two purposes: to convert the current output to a voltage or to limit internal power dissipation. The resistor is chosen to allow voltage headroom in the output circuitry at maximum output. For high di/dt measurements more headroom is necessary so that current can be established faster in the inductive coil.
Frequency response can be separated into two overlapping regions. In the first region, the electronic operation mode, the response remains excellent until the compensation current weakens due to the amplifier’s inability to counteract the circuit’s stray capacity. At this point the amplifier behaves like a capacitor shunting high frequency signals to the supply common.
In the second region, the transducer operates in the intensity transformer mode, recovering its normal value before weakening again. The compensation coil now operates as a current transformer connected to the output. The transformer effect is far from ideal; however, diligent adjustment of circuit characteristics results in a smooth transition between both operating regions. Bandwidths reaching 300kHz can be realized. Units are capable of accurately tracking current rise times from 50 A/µsec to over 200 A/µsec. This is why they are frequently used to protect semiconductors.
The intensity transformer effect also increases the sensors ability to capture transients. Most transients will not cause damage but may not always be measured due to saturation. If the current sharply exceeds the nominal value the core may become magnetized, causing an offset output. To remedy this, the core must be demagnetized. For 300A units with no magnetic offset and zero input, the typical output offset is <0.3mA.



Magnetoresistive Current Sensors

Magnetoresistive (MR) devices, originally designed for sensitive high-speed disk drive heads, measure an induced magnetic field by detecting a change in the sensing material resistance depending on the incident magnetic field. Because the MR element is much more sensitive than a traditional Hall element, these transducers may be compensated in a fashion similar to the closed-loop Hall sensor, but without the need for a flux-concentrating core or multiple compensation windings. The primary's field is detected by a sensor element in the form of a Wheatstone bridge. Using a special layout arrangement, the sensor detects only magnetic field gradients and rejects the ambient field. The device's current compensation ratio does not depend on a turns ratio, but rather on the ratio of fields impinging on the MR elements from both the primary turn and compensation turn.



Compared to traditional Hall Elements, these sensors feature smaller size but a slightly lower bandwidth and a limited variety of current ranges. Their coreless design makes them free of both the advantages and disadvantages of the transformer effect.

The absence of a core allows MR devices to be integrated directly into a hybrid module. To provide voltage isolation, the solid primary conductor is mounted on the bottom of the substrate. Their small size, low weight and "wire-free" packaging suit these sensors to many applications requiring the measurement of AC and DC currents to 50A.

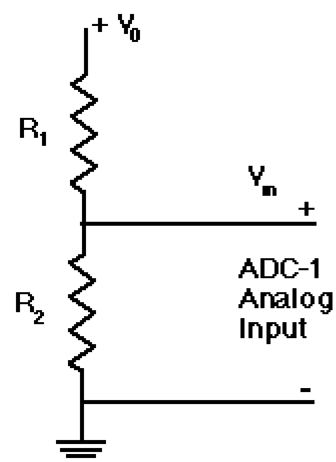
Voltage sensors

Voltage Divider

AC line voltage is easy to monitor with a relatively easy sensor to build. By using two resistors in a voltage divider configuration, voltage output from the power supply can be scaled down to the input range of the A/D Convertor.

The resistors also provide a fixed load for the power supply. As long as the load is fixed, any variations in output voltage are due to a varying AC line voltage. The ratio of the resistor values (which determines the divider scale) will depend on the output voltage from the chosen power supply.

Although very simple, this technique works very well.



V_0 is the input voltage to the divider (i.e. the raw signal output from the sensor), and V_m is the voltage digitized by the ADC-1 after passing through the divider.

Since the current passing through each resistor is the same, by Ohm's Law,

$$\frac{V_0}{R_1 + R_2} = \frac{V_m}{R_2}$$

The voltage output by the sensor is the voltage measured by the ADC-1 times a factor dependent on the resistor values:

$$V_0 = \left(\frac{R_1 + R_2}{R_2}\right) \cdot V_m \, .$$

where V_m is the voltage measured by the ADC-1.

In electrically noisy environments it may be advisable to use shielded cable. Long unshielded sensor leads may act as antennas and pickup unwanted signals. Shielded cables also provide mechanical protection of the interior wires from abrasion and other hazards. In most cases, the shield consists of a foil layer wrapped around the interior wires, and then covered with a plastic protective jacket.

When checking the installation of your sensors, you may notice that the values returned by the data acquisition system appear to be very noisy and variable. A likely cause of this condition is that the ground of your sensor is floating relative to the ground of the ADC-1 sensor interface. Since voltages are measured relative to a baseline level, commonly called "ground", it is easy to see that measurement problems can occur if the ground of the sensor, and the ground of the data acquisition system, are not at the same level.
If grounding the input does not reduce the noise to an acceptable level, you may need to filter the input. By placing a small capacitor (10-100 μF) across the input, high frequency spikes will be eliminated. But keep in mind, as larger capacitors are used, lower frequencies are filtered and you may not be able to observe rapid changes in sensor output.

Voltage Transformers

High-Values of monitored voltages can be stepped-down to the level which is suitable for the operational amplifiers by means of transformers.

Hall Effect voltage sensors

There are many other possibilities to obtain isolated voltages and it should be noted that the so-called LEM modules (manufactured by Liaisons Electroniques Mecaniques, S.A. Geneve) are frequently used. For voltage measurements a LEM module is connected in parallel across the terminals where the voltage is t be monitored. The main advantages of the use of the LEM modules are: high level of galvanic isolation, wide measuring range and high overload capability, high bandwidth (e.g. 100 kHz), high accuracy (e.g. 0.2%), good sensitivity, easy installation, etc.

Speed/Position Sensors

The instantaneous rotor speed ω can be measured using a DC tachogenerator or an AC tachogenerator. The rotor speed can also be detected without the need to use any tacho, by measuring the rotor position (rotor angle ϑ) with high-resolution method, for example an encoder, and using the rotor angle to obtain the rotor speed ($\omega = \mathrm{d}\vartheta/\mathrm{d}t$). The rotor acceleration can be obtained by taking the first derivative of the angular rotor speed. Similarly, electromagnetic resolvers can also be used for speed measurement, especially in applications which do not require high-speed applications. The rotor position is usually measured using optical encoders or electromagnetic resolver.

DC Tachometers

Tachometers can be used for monitoring the angular speed of a shaft. For this purpose it is possible to use a DC tachometer which can be a separately excited DC machine. When this machine operates as a generator, and if the field current is constant, under certain assumprions its armature voltage is proportional to the angular rotor speed.
It should be noted that due to the commutators and also due to the fact that the number of the rotor slots is usually large, the voltage across the armature contains unwanted ripples. It follows that it can be advantageous to use such a tacho , which does not have commutators and brushes. However, it should be noted that when a DC tacho is used and the number of commutator segments is high, the frequency of the noise is relatively high compared with the speed signal frequency. Thus the peed signal has to be filtered by a low-pass filter.

AC Tachometers

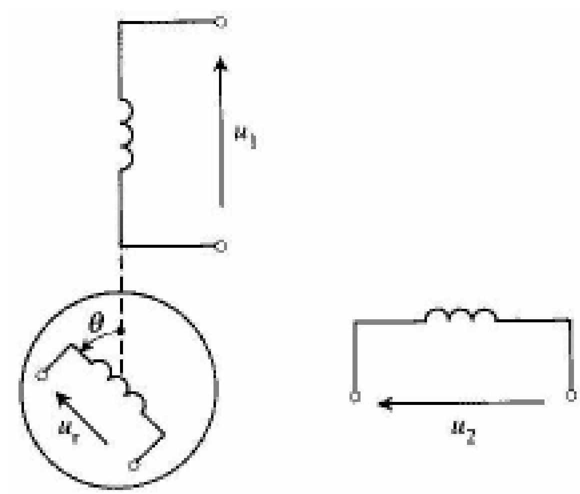
It is possible to employ the two-phase induction servomotor as an AC tacho. In this case this machine is used, which has two windings on its stator, and these are in space quadrate. The rotor can have a squirrel-cage or there can be a so-called drag-cup (aluminum cup) rotor.

The main winding of the machine is supplied by an AC voltage with constant magnitude and frequency *f*. For measuring the rotor speed, it is utilized than when the rotor of the machine is driven at an angular speed ω, a voltage is induced in the auxiliary winding (output winding), whose frequency is *f*, but in a specific speed range the magnitude of this induced voltage is proportional to the angular speed ω. When the rotor is at standstill, there is no voltage induced in the auxiliary winding.

Encoders

Optical encoders are one of the most widely used position sensors. In one form of the encoder. A low inertia disc or plate containing opaque and transparent segments rotates between a LED device (e.g. a photo transistor, a photodiode, etc.) and a light detector to pulse light. Encoders are classified as incremental or absolute encoders. Absolute encoders are very expensive. In incremental encoders, the disc contain uniform patterns of equally spaced radial lines to produce detector pulses that are countered to determine the position of the shaft relative to a reference. Most encoders have two sets of light detectors, each of which output a different waveform (A and B). The second output waveform is 90° out of phase of the first waveform. The manner in which one waveform lags or leads the other can be used to determine the direction of the rotation of the shaft.

Resolvers



Electromagnetic resolvers are becoming increasingly popular for measuring the rotor position, due to their more rugged construction and higher operating temperatures, when compared to encoders and the decreasing price of resolver-to-digital converters. The resolver inherently provides an absolute position angle. The resolver has two stator windings (cosine and sine) which re in space quadrature and a rotor winding. In conventional resolver the air-gap is cylindrical. The schematic of the conventional electromagnetic resolver is shown in the figure on the right.
In a conventional resolver there is a wound rotor, and the rotor winding is supplied by a sine wave reference voltage through slip rings and bushes or a rotating transformer. The reference voltage can be described as

$$u_r(t) = U_m \sin(\omega_1 t) \, .$$

It should be noted that it is also possible to generate digitally the sine reference voltage using a counter, a read-only-memory programmed with a sine function and a D/A converter. The voltages induced in the two stator windings are as follows, if ideal conditions are assumed

$$u_1(t) = cU_m \cos\Theta \sin(\omega_1 t) = U_1 \sin(\omega_1 t)$$

$$u_2(t) = cU_m \sin\Theta \sin(\omega_1 t) = U_2 \sin(\omega_1 t)$$

where c is a constant (it depends on the turns ratio of the stator and rotor windings) and Θ is the rotor angle. It follows that the amplitudes U_1 and U_2 of the induced voltages depend on the rotor position

$$U_1 = cU_m \cos\Theta$$

$$U_2 = cU_m \sin\Theta \, .$$

Two output signals of the resolver can be sampled, and by using A/D conversion, they can be converted into digital signals. It then follows from equations above that when these two signals are divided,

$$\frac{u_2(t)}{u_1(t)} = \tan\Theta$$

is obtained, and thus by using a division of the two signals, and by producing the arctan function with the help of a look-up-table, the rotor position Θ is obtained.
In practice a resolver can generate non-ideal signals which differ from the ideal situation described above, and these result in position error. The most common sources of the non-ideal characteristics of a resolver are: voltage amplitude asymmetry, stator asymmetry, space harmonics, time harmonics in the rotor excitation voltage, and there can also be disturbance signals.

Signal Conditioning

Regardless of the types of sensors or transducers you are using, the proper signal conditioning equipment can improve the quality and performance of your system.
The electrical signals generated by the transducers must be optimized for the input range of the DAQ board. Signal conditioning accessories can amplify low-level signals, and then isolate and filter them for more accurate measurements. In addition, some transducers require voltage or current excitation to generate a voltage output.

Amplification

Unwanted noise can play havoc with the measurement accuracy of a PC-based DAQ system. The effects of system noise on your measurements can be extreme if you are not careful. Signal conditioning circuitry with amplification, which applies gain outside of the PC chassis and near the signal source, can increase measurement resolution and effectively reduce the effects of noise.
For the highest possible accuracy, the signal should be amplified so that the maximum voltage range of the conditioned signal equals the maximum input range of the analog-to-digital converter (ADC).
An amplifier, whether located directly on the DAQ board or in external signal conditioners, can apply gain to the small signal before the ADC converts the signal to a digital value. Boosting the input signal uses as much of the ADC input range as possible.
However, many transducers produce voltage output signals on the order of milivolts or even microvolts. Amplifying these low-level analog signals directly on the DAQ board also amplifies any noise picked up from the signal lead wires or from within the computer chassis. When the input signal is as small as microvolts, this noise can drown out the signal itself, leading to meaningless data.
A simple method for reducing the effects of system noise on your signal is to amplify the signal as close to the source as possible, which boosts the analog signal above the noise level before noise in the lead wires or computer chassis can corrupt the signal.

Filtering and Averaging

You can also use filters to reject unwanted noise within a certain frequency range.
A noise filter is used on DC-class signals such as temperature to attenuate higher frequency signals that can reduce the accuracy of your measurement.
AC-class signals such as vibration often require a different type of filter known as an antialiasing filter. Like the noise filter, the antialiasing filter is also a lowpass filter; however, it must have a very steep cutoff rate, so that it almost completely removes all frequencies of the signal that are higher than the input bandwidth of the board. If the signals were not removed, they would erroneously appear as signals within the input bandwidth of the board.
Many systems will exhibit 50/60 Hz periodic noise components from sources such as power supplies or machinery. Lowpass filters on your signal conditioning circuitry can eliminate unwanted high-frequency components. However, be sure to select the filter bandwidth carefully so that you do not affect the time response of your signals.
Although many signal conditioners include lowpass noise filters to remove unwanted noise, an extra precaution is to use software averaging to remove additional noise. Software averaging is a simple and

effective technique of digitally filtering acquired readings; for every data point you need, the DAQ system acquires and averages many voltage read-ings.
For example, a common approach is to acquire 100 points and average those points for each measurement you need. For slower applications in which you can oversample in this way, averaging is a very effective noise filtering technique.

Isolation

Improper grounding of the DAQ system is the most common cause of measurement problems and damaged DAQ boards. Isolated signal conditioners can prevent most of these problems by passing the signal from its source to the measurement device without a galvanic or physical connection. Isolation breaks ground loops, rejects high common-mode voltages, and protects expensive DAQ instrumentation.
Common methods for circuit isolation include using optical, magnetic, or capacitive isolators. Magnetic and capacitive isolators modulate the signal to convert it from a voltage to a frequency. The frequency can then be transmitted across a transformer or capacitor without a direct physical connection before being converted back to a voltage value.
When you connect your sensor or equipment ground to your DAQ system, you will see any potential difference in the grounds on both inputs to your DAQ system. This voltage is referred to as common-mode *voltage*. If you are using a single-ended measurement system, the measured voltage includes the voltage from the desired signal as well as this common-mode voltage from the additional ground currents in the system.

If you are using a DAQ board with differential inputs, you can reject some of this common-mode voltage, typically up to 12 V. However, larger ground potential differences, or ground loops, will damage unprotected DAQ devices. If you cannot remove the ground references, use isolating signal conditioners that break these ground loops and reject very large common-mode voltages.
Isolators also provide an important safety function by protecting against high-voltage surges from sources like power lines, lightning, or high-voltage equipment. When dealing with high voltages, a surge can damage the equipment or even harm equipment operators. By breaking the galvanic connection, isolated signal conditioners produce an effective barrier between the DAQ system and these high-voltage surges.

Multiplexing

Signal conditioners equipped with signal multiplexers can cost-effectively expand the input/output (I/O) capabilities of your plug-in DAQ board. The typical plug-in DAQ board has 8 to 16 analog inputs and 8 to 24 digital I/O lines. External multiplexers can increase the I/O capacity of a plug-in board to hundreds and even thousands of channels.
Analog input multiplexers use solid-state or relay switches to sequentially switch, or *scan*, multiple analog input signals onto a single channel of the DAQ board. For higher speed applications, be sure that the multiplexing circuit, as well as the DAQ board, can operate at the needed scanning rates.

Signal conditioning devices for analog signals often provide multiplexing for use with slowly changing signals such as temperature. The ADC samples one channel, switches to the next channel, samples it, switches to the next channel, and so on. Because the same ADC is sampling many channels instead of one, the effective sampling rate of each individual channel is inversely proportional to the number of channels sampled.

It is important to understand the nature of your signal, the configuration that is being used to measure the signal and the affects of the surrounding environment. Based on this information you can easily determine whether signal conditioning will be a necessary part of your DAQ system.

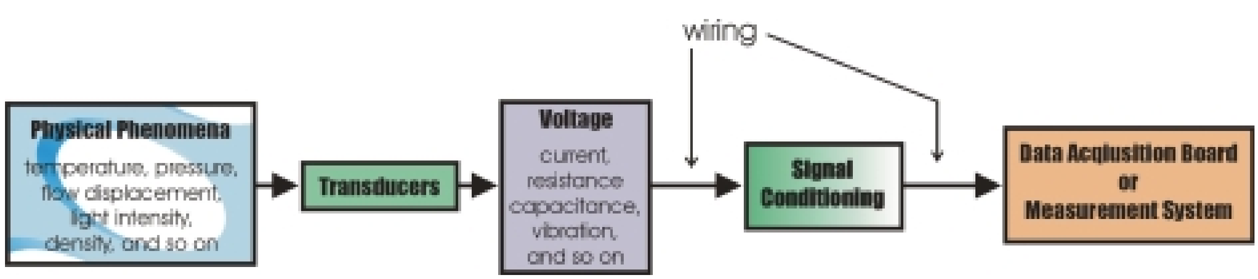
DAQ Hardware

The analog input specifications can give you information on both the capabilities and the accuracy of the DAQ product. Basic specifications, which are available on most DAQ products, tell you the number of channels, sampling rate, resolution, and input range. The number of analog channel inputs will be specified for both single-ended and differential inputs on boards that have both types of inputs. Single-ended inputs are all referenced to a common ground point. These inputs are typically used when the input signals are high level (greater than 1 V), the leads from the signal source to the analog input hardware are short (less than 15 ft.), and all input signals share a common ground reference. If the signals do not meet these criteria, you should use differential inputs. With differential inputs, each input has its own ground reference. Noise errors are reduced because the common-mode noise picked up by the leads is canceled out.

Sampling Rate – This parameter determines how often conversions can take place. A faster sampling rate acquires more points in a given time and can therefore often form a better representation of the original signal.
Multiplexing – A common technique for measuring several signals with a single ADC is multiplexing. The ADC samples one channel, switches to the next channel, samples it, switches to the next channel, and so on. Because the same ADC is sampling many channels instead of one, the effective rate of each individual channel is inversely proportional to the number of channels sampled.
Resolution – The number of bits that the ADC uses to represent the analog signal is the resolution. The higher the resolution, the higher the number of divisions the range is broken into, and therefore, the smaller the detectable voltage change.
Range – Range refers to the minimum and maximum voltage levels that the ADC can quantize. The multifunction DAQ boards offer selectable ranges so that the board is configurable to handle a variety of different voltage levels. With this flexibility, you can match the signal range to that of the ADC to take best advantage of the resolution available to accurately measure the signal.

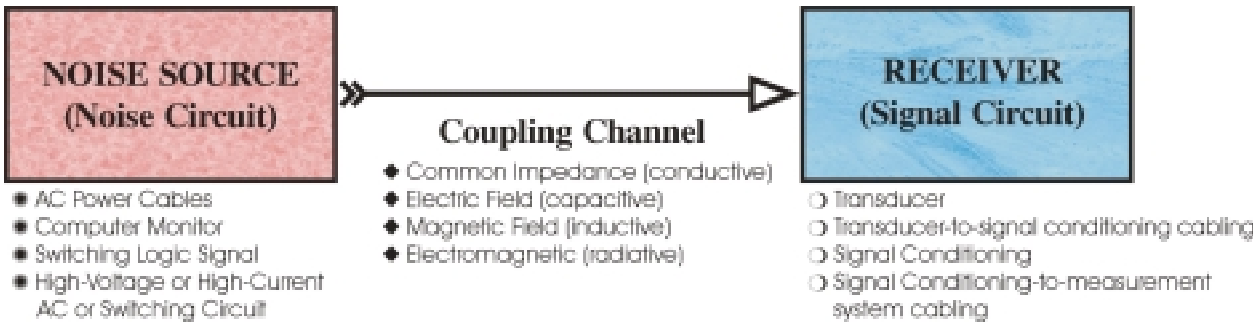
Minimizing Noise Coupling in the Interconnects

Unfortunately, measuring analog signals with a data acquisition board is not always as simple as wiring the signal source leads to the data acquisition board. Knowledge of the nature of the signal source, a suitable configuration of the data acquisition board, and an appropriate cabling scheme may be required to produce accurate and noise-free measurements. Figure bellow shows a block diagram of a typical data acquisition system. The integrity of the acquired data depends upon the entire analog signal path.



Even when a measurement setup avoids ground loops or analog input stage, the measured signal will almost inevitably include some amount of noise or unwanted signal “picked up” from the environment. This is especially true for low-level analog signals that are amplified using the onboard amplifier that is available in many data acquisition boards. To make matters worse, PC data acquisition boards generally have some digital input/output signals on the I/O connector. Consequently, any activity on these digital signals provided by or to the data acquisition board that travels across some length in close proximity to the low-level analog signals in the interconnecting cable itself can be a source of noise in the amplified signal. In order to

minimize noise coupling from this and other extraneous sources, a proper cabling and shielding scheme may be necessary.
Before proceeding with a discussion of proper cabling and shielding, an understanding of the nature of the interference noise-coupling problem is required. There is no single solution to the noise-coupling problem. Moreover, an inappropriate solution might make the problem worse.
An interference or noise-coupling problem is shown in the following figure.



There are four principal noise “pick up” or coupling mechanisms – conductive, capacitive, inductive, and radiative. Conductive coupling results from sharing currents from different circuits in a common impedance. Capacitive coupling results from time-varying electric fields in the vicinity of the signal path. Inductive or magnetically coupled noise results from time-varying magnetic fields in the area enclosed by the signal circuit. If the electromagnetic field source is far from the signal circuit, the electric and magnetic field coupling are considered combined electromagnetic or radiative coupling.

Solving Noise Problems in Measurement Setups

Solving noise problems in a measurement setup must first begin with locating the cause of the interference problem.
Noise problems could be anything from the transducer to the data acquisition board itself. A process of trial and elimination could be used to identify the culprit.
The data acquisition board itself must first be verified by presenting it with a low-impedance source with no cabling and observing the measurement noise level. This can be done easily by short circuiting the high and low signals to the analog input ground with as short a wire as possible, preferably at the I/O connector of the data acquisition board. The noise levels observed in this trial will give you an idea of the best case that is possible with the given data acquisition board. If the noise levels measured are not reduced from those observed in the full setup (data acquisition board plus cabling plus signal sources), then the measurement system itself is responsible for the observed noise in the measurements. If the observed noise in the data acquisition board is not meeting its specifications, one of the other boards in the computer system may be responsible.
Try removing other boards from the system to see if the observed noise levels are reduced. Changing board location, that is, the slot into which the data acquisition board is plugged, is another alternative.
The placement of computer monitors could be suspect. For low-level signal measurements, it is best to keep the monitor as far from the signal cabling and the computer as possible. Setting the monitor on top of the computer is not desirable when acquiring or generating low-level signals.
Cabling from the signal conditioning and the environment under which the cabling is run to the acquisition board can be checked next if the acquisition board has been dismissed as the culprit. The signal conditioning unit or the signal source should be replaced by a low-impedance source, and the noise levels in the digitized data observed. The low-impedance source can be a direct short of the high and low signals to the analog input ground. This time, however, the short is located at the far end of the cable. If the observed noise levels are roughly the same as those with the actual signal source instead of the short in place, the cabling and/or the environment in which the cabling is run is the culprit.

Cabling reorientation and increasing distance from the noise sources are possible solutions. If the noise source is not known, spectral analysis of the noise can identify the interference frequencies, which in turn can help locate the noise source. If the observed noise levels are smaller than those with the actual signal source in place, however, a resistor approximately equal to the output resistance of the source should be tried next in place of the short at the far end of the cable. This setup will show whether capacitive coupling in the cable due to high source impedance is the problem. If the observed noise levels from this last setup are smaller than those with the actual signal in place, cabling and the environment can be dismissed as the problem. In this case, the culprit is either the signal source itself or improper configuration of the data acquisition board for the source type.

Triggers

Many DAQ applications need to start or stop a DAQ operation based on an external event. Digital triggers synchronize the acquisition and voltage generation to an external digital pulse. Analog triggers, used primarily in analog input operations, start or stop the DAQ operation when an input signal reaches a specified analog voltage level and slope polarity.

The Personal Computer

The computer used for your data acquisition system can drastically affect the maximum speeds at which you are able to continuously acquire data. Today’s technology boasts Pentium and PowerPC class processors coupled with the higher performance PCI bus architecture as well as the traditional ISA bus and USB. With the advent of PCMCIA, portable data acquisition is rapidly becoming a more flexible alternative to desktop PC based data acquisition systems.

For remote data acquisition applications that use RS-232 or RS-485 serial communication, your data throughput will usually be limited by the serial communication rates.

The data transfer capabilities of the computer you use can significantly affect the performance of your DAQ system.

All PCs are capable of programmed I/O and interrupt transfers. DMA transfers, not available on some computers, increases the system throughput by using dedicated hardware to transfer data directly into system memory. Using this method, the processor is not burdened with moving data and is therefore free to engage in more complex processing tasks. To reap the benefits of DMA or interrupt transfers, the DAQ board you choose must also be capable of making these types of transfers.

The limiting factor for acquiring large amounts of data is often the hard drive. Disk access time and hard drive fragmentation can significantly reduce the maximum rate at which data can be acquired and streamed to disk. For systems that need to acquire high-frequency signals, you should select a high-speed hard drive for your PC and make sure that there is enough contiguous (unfragmented) free disk space to hold the data.

Applications requiring real-time processing of high-frequency signals need a high-speed, 32-bit processor with its accompanying coprocessor, or a dedicated plug-in processor such as a digital signal processing (DSP) board. If the application only acquires and scales a reading once or twice a second, however, a low-end PC can be satisfactory.

You must also look ahead to determine which operating system and computer platform will yield the greatest long term return on investment and still able to meet your short term goals. Factors that may influence your choice may include the experience and needs of both your developers and end users, other uses for the PC both now and in the future, cost constraints, and the availability of different computers with respect to your implementation time frame. Traditional platforms include Mac OS, which is known for its simple graphical user interface, and Windows 3.x. Windows 9x, which boasts a much improved user interface over Windows 3.x, also offers the option of Plug and Play hardware configuration. In addition, Windows NT 4.0 offers a more robust 32-bit OS with the look and feel of Windows 9x.

Software

Software transforms the PC and DAQ hardware into a complete DAQ, analysis, and display system. DAQ hardware without software is useless – and DAQ hardware with poor software is almost useless. The majority of DAQ applications use driver software. Driver software is the layer of software that directly programs the registers of the DAQ hardware, managing its operation and its integration with the computer resources, such as processor interrupts, DMA, and memory. Driver software hides the low-level, complicated details of hardware programming, providing the user with an easy-to-understand interface.
While selecting driver software, there are several factors to consider.
Which Functions Are Available? – Driver functions for controlling DAQ hardware can be grouped into analog I/O, digital I/O, and timing I/O. Although most drivers will have this basic functionality, you will want to make sure that the driver can do more than simply get data on and off the board. Make sure the driver has the functionality to:

- Acquire data at specified sampling rates
- Acquire data in the background while processing in the foreground
- Use programmed I/O, interrupts, and DMA to transfer data
- Stream data to and from disk
- Perform several functions simultaneously
- Integrate more than one DAQ board
- Integrate seamlessly with signal conditioning equipment

Which Operating Systems Can You Use with the Driver? – Make sure that the driver software is compatible with the operating systems you plan to use now and in the future. The driver should also be designed to capitalize on the different features and capabilities of the OS. For example, while drivers written for Windows 3.x may run under Windows 95, only drivers written in full 32-bit code for Windows 95 can take advantage of the increased performance and robustness available with Windows 95. Drivers for Windows 95 should also be able to work together with Windows 95 Plug and Play to ensure that your system is easy to set up and configure.
Which Programming Languages Can You Use with the Driver? – Make sure that the driver can be called from your favorite programming language, and is designed to work well within that development environment.
Are the Hardware Functions You Need Accessible in Software? – A problem occurs when a developer purchases DAQ hardware, then combines the hardware with software, only to find that a required hardware feature is not handled by the software. The problem occurs most frequently when the hardware and software are developed by different companies. By asking this question, you can save yourself time searching through the software manuals looking for a function that does not exist.

Application Software

An additional way to program DAQ hardware is to use application software. But even if you use application software, it is important to know the answers to the previous questions, because the application software will use driver software to control the DAQ hardware. Application software adds analysis and presentation capabilities to the driver software. Application software also integrates instrument control (GPIB, RS-232, and VXI) with data acquisition.

Data acquisition and instrument control software development environments offer a variety of methodologies and development strategies, from menu-driven customized applications to full-fledged programming environments. Advanced instrumentation systems require the flexibility and power of a general-purpose programming language, such as C or BASIC. Also, building PC-based instrumentation systems requires a significant effort to successfully integrate various data collecting and analysis devices into your programs. This suggests that customized software packages for instrumentation are a must for serious system development.

Caught in the middle of these varying approaches to software development is the test engineer or data acquisition system developer. On the one hand, the instrumentation system developer needs a software solution that can grow and expand as system parameters change in the future—like C. But, developers must also get the system up and running quickly to ensure feasibility, performance, and hardware compatibility.

LabWindows/CVI

Most scientists and engineers developing instrumentation programs today agree that C supplies the power and flexibility they need for advanced applications. Unfortunately, C continues to suffer from the perception that it is only a high-powered language for advanced programmers.

Many scientists and engineers are intimidated by the aspects of moving from simplified BASIC environments to the cryptic, more structured world of C. These scientists and engineers are strongly attached to the development methodology of the interpreted, interactive BASIC programming environment. LabWindows/CVI has tools, called *function panels*, used for interactively developing and executing functions without writing a single line of C source code. Developers can experiment with library functions or sections of test code without writing a C program to do it. This interactive interface makes LabWindows/CVI a perfect environment for less sophisticated programmers to get things up and running quickly. With function panels, you can easily and automatically generate the syntax for calling LabWindows/CVI library functions.

Acknowledgements

The most information in this document, inclusive of figures, was drawn from National Instruments Application Notes (www.ni.com) and PCIM Magazine (www.pcim.com).

Other References

Vas, P.: Parameter Estimation, Condition Monitoring and Diagnosis of Electrical Machines, Oxford University Press, New York, 1993