

**Ultrasonic Flow Sensors**

Ultrasonic flow sensors can be divided into Doppler sensors and transit, or time-of-travel, sensors. Doppler sensors measure the frequency shifts caused by liquid flow. Two transducers are mounted in a case attached to one side of the pipe; a signal of a known frequency is delivered to the liquid to be measured. Bubbles, solids or any other discontinuity in the liquid cause the pulse to be reflected to the receiver element. Because the liquid that causes the reflection is moving, the frequency of the returned pulse shifts, and the frequency shift is proportional to the velocity of the liquid. With transit, or time-of-travel, meters, transducers are mounted on each side of the pipe, such that the sound waves traveling between the devices are at a 45-degree angle to the direction of liquid flow. The speed of the signal moving between the transducers increases or decreases with the direction of transmission and the velocity of the liquid being measured. A time-differential relationship proportional to the flow can be obtained by transmitting the signal alternately in both directions. One limitation of this type of sensor is that the liquids that are being measured have to be relatively free of solids or entrained gases in order to minimize signal scattering and absorption. Advantages of ultrasonic flow meters are that they are non-intrusive and their cost is moderate. Many models are designed to clamp onto existing pipe.

**Optical encoder**

Among the most popular position measuring sensors, optical encoders find use in relatively low reliability and low resolution applications. An *incremental* optical encoder is a disc divided into sectors that are alternately transparent and opaque. A light source is positioned on one side of the disc, and a light sensor on the other side. As the disc rotates, the output from the detector switches alternately on and off, depending on whether the sector appearing between the light source and the detector is transparent or opaque. Thus, the encoder produces a stream of square wave pulses which, when counted, indicates the angular position of the shaft. Available encoder resolutions (the number of opaque and transparent sectors per disc) range from 100 to 65,000, with absolute accuracies approaching 30 arc-seconds (1/43,200 per rotation). Most incremental encoders feature a second light source and sensor at an angle to the main source and sensor, to indicate the direction of rotation. Many encoders also have a third light source and detector to sense a onceper- revolution marker. Without some form of revolution marker, absolute angles are difficult to determine. A potentially serious disadvantage is that incremental encoders require external counters to determine absolute angles within a given rotation. If the power is momentarily shut off, or if the encoder misses a pulse due to noise or a dirty disc, the resulting angular information will be in error.

**Force sensor types**

Quartz force sensors are ideally designed and suited for the measurement of dynamic oscillating forces, impact, or high speed compression/tension forces. The basic design utilizes the piezoelectric principle, where applied mechanical stresses are converted into an electrostatic charge that accumulates on the surface of the crystal. The quartz crystals of a piezoelectric force sensor generate an electrostatic charge only when force is applied to or removed from them. In other words, if you apply a static force to a piezoelectric force sensor, the electrostatic charge output initially generated will eventually leak away and the sensor output ultimately will return to zero.

****

**Accelerometers**

Piezoelectric accelerometers are self-generating devices characterized by an extended region of flat frequency response range, a large linear amplitude range and excellent durability. These inherent properties are due to the use of a piezoelectric material as the sensing element for the sensor. Piezoelectric materials are characterized by their ability to output a proportional electrical signal to the stress applied to the material. The basic construction of a piezoelectric accelerometer is depicted in below figure.



**Magnetometers**

The flux gate magnetometer relies on measurement of the behavior of a ferromagnetfilled inductor. In the absence of external magnetic fields, current passed through the coil causes the formation of a magnetic field, which acts to polarize the ferromagnetic material. In general, the memory of the ferromagnetic material causes a hysteresis in the relation between the applied field and the polarization of the ferromagnet. We can see this by thinking about the starting situation, where the ferromagnet is unpolarized and there is no current. If a current is applied, it polarizes the ferromagnet. As the current is increased, the polarization increases until saturation. Now, the current may be reduced to zero, and the resulting situation will include some residual polarization of the ferromagnet. If a current in the opposite direction is applied, the polarization is reversed, eventually saturated, and retains some residual reverse polarization when the current is again turned off. The applied magnetic field is proportional to the current through the electromagnetic field and we see that the magnetization of the core responds to the applied field with hysteresis. In the absence of an external magnetic field, the hysteresis loop is perfectly symmetric, and the graph of voltage versus current would only include the odd harmonics of the drive frequency.

If there is an external magnetic field, the hysteresis loop is shifted away from the origin. This is because there is a residual applied magnetic field when the current is off, due to the external magnetic field. One result of this is that the symmetry of the hysteresis loop is spoiled. If the I-V graph is analyzed, there will be a component at the second harmonic of the drive frequency, and the amplitude of this harmonic will be proportional to the component of the external magnetic field vector along the coil axis. Therefore, this device may be used to sense external magnetic fields. In fact, when properly constructed and wired, this sort of sensor can be very sensitive to small changes in external magnetic field. This class of magnetometers is generally used for space science missions, and for all precision terrestrial applications. A miniature flux-gate magnetometer is available from Applied Physics Systems, featuring resolution of less than 10−10 T/sqrt(Hz), very good linearity, and very small size. It is a fairly expensive instrument. This style of magnetometer is also used for a number of prospecting applications. In several important applications, buried objects produce magnetic fields, and instruments that can measure local magnetic field gradients are very useful. Instruments available from Schonstedt feature a pair of flux gate magnetometers operated in a differential mode. If magnetic objects are positioned near the pair, the earth’s magnetic field is distorted and the difference between the two magnetometers does not cancel perfectly. In this mode, the gradiometer can sense the presence of a magnetic object. This kind of instrument is commonly used by road-repair crews to locate buried cables prior to digging.

Another class of magnetometer is called the Hall effect sensor. In the Hall effect sensor, the transport of electrons through an electrical device is affected by the presence of an external magnetic field. In general, a Hall effect sensor can measure down to about 5% of the earth’s magnetic field.

References

[1] Jon Wilson, *Sensor technology handbook,* Elsevier Inc, 2005.

[2] M.W. Spong, S. Hutchinson, M. Vidyasagar,*Robot Modeling and Control*, John Wiley & Sons, Inc., 2005