A Technology Comparison of the DIST Non-Contact Position Sensor with LVDT's and Magnetostrictive Sensors

By
Leonard Goldman, PhD - Director of R&D

LRT Sensors LLC

114 Windsor Ave, Suite 110, Narberth, PA 19072
Email: info@lrtsensors.com
Tel: 877-299-8595
Fax: 877-299-0844

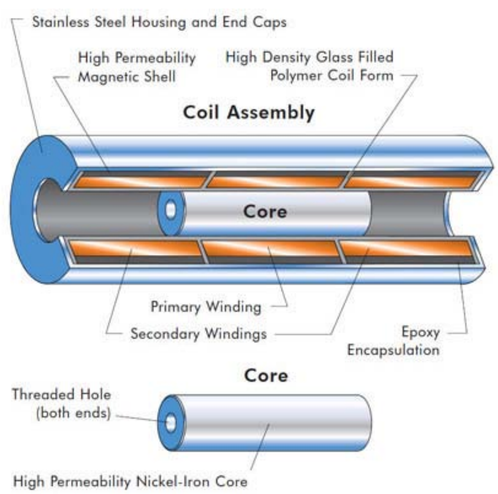
LRT Sensors designs and manufactures a standard series of non-contact linear sensors using our patented DIST (**D**istributed **I**mpedance **S**ensor **T**echnology) technology. This know-how is also applicable to rotary, gap sensing and liquid level applications on a custom basis. LRT's sensors compare favorably to traditional technologies such as LVDT's and magnetostrictive sensors from a cost, accuracy and resolution perspective and are impervious to harsh environments such as high temperature (225° C), high magnetic fields, high shock and vibration and high radiation. They are used in a wide variety of applications in the aircraft, medical, recreation, farm and construction equipment industries. DIST sensors are easily adapted to replace existing LVDT's and magnetostrictive sensors and can readily be incorporated internally into hydraulic and pneumatic cylinders. The sensors have no wear parts and can therefore deliver long trouble-free service. This paper compares the DIST technology to that of LVDT's and magnetostrictive sensors.

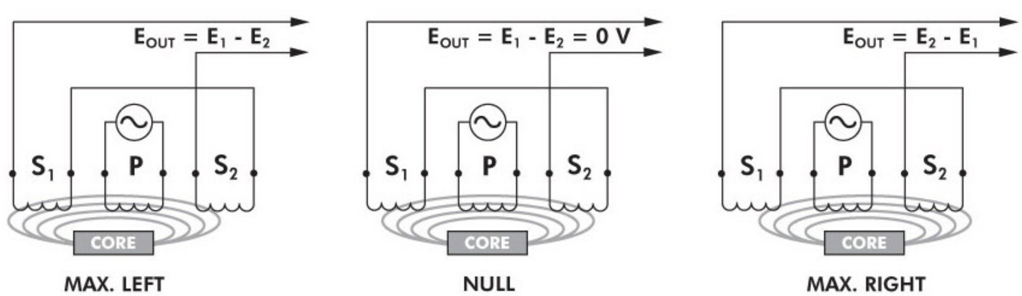
The DIST sensor, in a manner similar to inductive sensors, follows the fundamental laws of physics concerning changing electromagnetic fields. In a perfect vacuum an electromagnetic wave will travel forever at the speed of light in a straight line with no energy loss. However, if the electromagnetic wave encounters any material, the energy and the direction of the electromagnetic wave will be changed. The amount of the change can, in theory, be calculated by a set of equations called Maxwell's equations which is beyond the scope of this paper. A position sensor determines the change in the wave and from that we can calculate the presence and position of material in the wave's path. So, if something moves into the path of the electromagnetic wave, the wave will be distorted in a predictable manner. If we measure this distortion it is possible to determine the motion and or position of the material in the wave's path, i.e. a position sensor.

Two popular sensors used in applications similar to that of the DIST Sensor are LVDT's and magnetostrictive sensors. Below is a description of the three technologies.

LVDT (Linear Variable Differential Transformer)

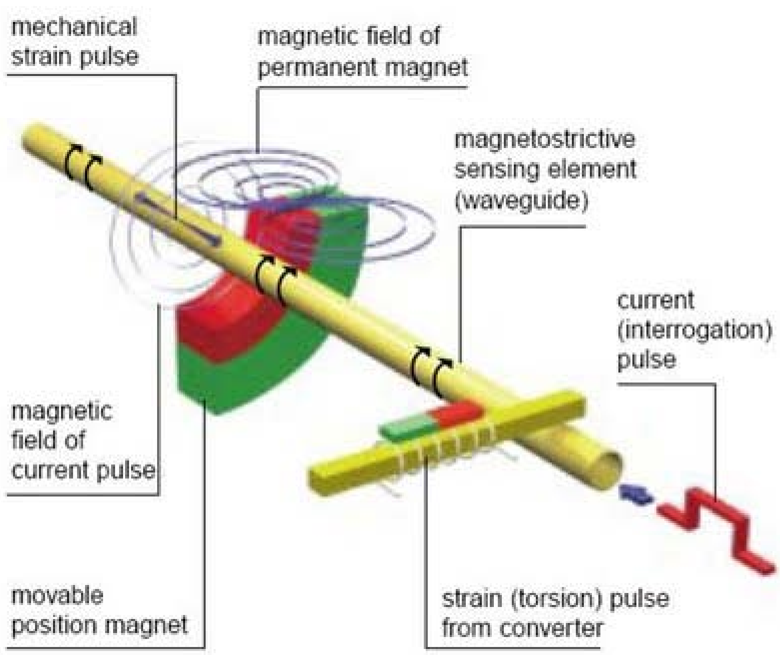
The LVDT is a non-contact inductive sensor technology that has been in use for 75 years. It is a variable transformer with a movable magnetic core. The LVDT has three wound coils; one primary and two secondary coils. A carefully calibrated AC voltage is injected into the primary coil and then transferred to the secondary coils via the coupling of the magnetic core, which is usually a soft iron rod. As the core's position changes, the output voltages in the secondary coils change thus producing a measure of the position of the core. A dedicated electronic module (a signal processor) provides the input signal, measures the output signal and provides a linear output after correcting for attenuations and phase changes in the wires. This electronic module can be located remotely from the coil, allowing the LVDT coil to operate in a harsh environment while the signal conditioner can be placed in a more benign location. An LVDT requires four to six wires between the coil and the signal analyzer and the wires and coils must be shielded to prevent interference from external magnetic fields. An LVDT also requires a dedicated signal processor for calibration. If the signal processor is replaced, the sensor must be recalibrated. Since the output signal from an LVDT is analog, system noise inevitably limits its ultimate resolution.





Magnetostrictive

Magnetostrictive sensors consist of a wire (the waveguide) that extends over the length of the measurement range. A permanent ring magnet, the position magnet, surrounds the wire and is attached to whatever is moving. The wire is selected so that when an electrical interrogation pulse is applied to the wire, an ultrasonic strainwave is generated at the location of the position magnet. The time elapsed between the generation of the strainwave and its detection at one end of the waveguide is indicative of the measured position. This sensor can be very long (meters) but has a slow response time due to the large transit times of acoustic pulses.The magnetostrictive sensor has one advantage over other sensors in that its resolution is 1 to 2 microns, independent of the length of the sensor. However, they do have environmental limitations in regard to temperature, shock and vibration. Their upper-temperature limit is only 100^{o}C. This temperature limitation is due to characteristics of the sensing element and not the electronics of the signal processor which is attached. The heart of the magnetostrictive sensor, the waveguide, is also susceptible to failure when used in high-shock and vibration applications. In some situations where space near the measurement point is limited, the signal processor can be located remotely. However, due to the high power requirements of the interrogation pulse and the weakness of the return signal, the distance between the processor and sensing element is limited to a few inches and must be carefully shielded. As with the LVDT, the sensor and signal processor must be calibrated as a unit and replacement of the signal processor requires recalibration.



DIST Linear Sensor

The DIST sensor consists of a double coil wound on a round non- conductive rod (usually fiberglass). The wire is wound as a helix with a large pitch. Upon reaching the end of the shaft, the pitch is reversed and a returning helix is laid over the first coil. This is shown in Figure 1 below where the enlarged view shows the position of both coils. In the electronics section, a simple circuit consisting of a single transistor is connected to the ends of the coil, producing a resonant circuit that oscillates in the 2-4 Mhz region. The result is two coils in series with one having current flowing clockwise and the other counterclockwise. The magnetic fields of these two coils are parallel to the sensor, point in opposite directions and cancel each other by the "right hand rule". At the same time the electric fields from these circulating currents are perpendicular to the rod and again, by the “right hand rule”, they are additive. The resulting electromagnetic field outside the coil is then mostly electric with a minimal magnetic component.

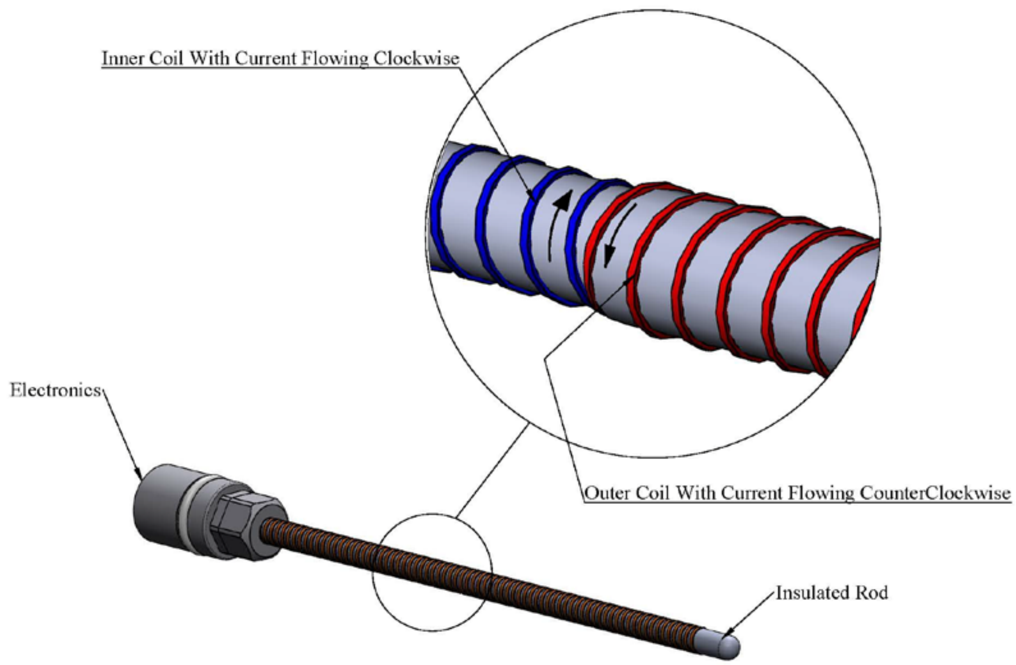


Figure 1

The frequency of this circuit is determined by the inductance (L) and capacitance (C) of the coil. Operating a circuit at its resonance frequency produces a very stable output (assuming that L and C remain constant). The inductance of the DIST design is low and constant, due to the few turns of the coil, but the ratio of capacitance to inductance is higher than in an inductive sensor and is based on the interaction of the strong electric field of the sensor with any nearby conductive surface. If we begin to cover the coil with a conductive surface, the capacitance and therefore the resonant frequency of the sensing element changes dramatically. We observe ~ 1 MHz changes in resonant frequency when the conductive surface moves the full length of the sensor. The change in frequency is linear with the movement of the conductive surface, can be transmitted great distances with no loss of information and is easily converted to a digital signal for further processing.

The output of the DIST sensor, as discussed above, is from a stable resonant circuit whose frequency is determined by the capacitance changes of the moving conductive surface. A typical sensor will have almost a one MHz change in frequency over the full range of motion. Since frequency can easily be measured to better than one part in one-million, this translates to a reproducibility (and accuracy after mapping) of better than one micron over sensor lengths up to one meter. The resolution of the sensor is sub-micron and is determined more by the quality of the frequency meter than the sensor itself.

In the DIST sensor there is no need to use extremely fine wire as with an LVDT. Wire diameter is intentionally minimized in an LVDT to produce a large inductance and a negligible capacitance, both LVDT characteristics. A DIST sensor can use a much heavier wire since it is desirable to maximize capacitance. A more robust wire becomes practical and is in fact advantageous. The heavier wire wound on a flexible rod can withstand extremely high levels of shock and vibration and overcomes these susceptibilities of other sensors.

Having an output that is a digital frequency rather than a voltage has many advantages. The amplitude of a frequency signal in the DIST system is not significant so long as it remains above the threshold of detection. Typical inductive sensors have analog outputs which make them susceptible to noise, attenuations and other distortions. They require that the system electronics be near to the sensor or have extensive correction software to compensate for these errors. Because of these and other problems it is difficult for an analog sensor to have accuracies better than one part in one-thousand of (0.1%) of full scale. As discussed above, the DIST sensor accuracy is one part in one-million (0.0001%) of full scale. The frequency signal can be replicated and sent over separate wires for redundancy or multiplexed giving it great flexibility in its mode of transmission. In addition, since the signal analyzer is nothing more than a frequency counter, the DIST sensor does not lose its calibration if it becomes necessary to change the electronics in the signal analysis portion.

The electronic section of the DIST sensor requires only a single active device (an inverter) which is readily available in operating temperatures of 225^{o}C and high radiation versions. The output frequency can be piggybacked on the DC power so that only one wire is required and the receiver can be located remotely. All of this circuitry (along with a temperature sensor to be discussed later) easily fits on a very small circuit board. This gives the DIST sensor the ability to operate in harsh environments with only a single wire (plus a ground) to transmit information to a remote computer. Additionally, the ability to have a signal wire in excess of 10 meters in length, and longer with repeaters, allows great flexibility in locating the signal analysis electronics. In many applications a frequency meter is already in place and can make the measurement without additional complexity.

The DIST sensor utilizes a single dual-helix coil (not a ratio of coils as in the LVDT) that is slightly more sensitive to temperature changes than comparable technologies. To compensate for this change, the DIST sensor has an integral temperature sensor whose output is converted to a lower frequency, transmitted on the single wire and used to correct these changes.

The DIST sensor, having its signals multiplexed on to the single wire output, requires a simple passive filter network at the receiving end so as to direct them to their respective frequency meters. In applications that do not require operation in hazardous conditions and/or have no space limitation, the conversion of the frequency to standard outputs can be performed in an electronics module attached to the sensor. This eliminates the need for external filter networks but limits operation to temperatures below 125^{o}C and increases the size of the electronics package.

The DIST sensor compares favorably to LVDT's and magnetostrictive sensors from both an economic and technological perspective. The simplicity of its mechanical (no wear parts) and electronic systems makes the DIST sensor a low cost alternative while offering comparable or superior performance. The robust design allows for excellent service in high magnetic fields and high shock and vibration applications. The sensor can also easily be adapted to high temperature (225°C) and high radiation environments. The single wire output also simplifies the selection of the location of the signal analysis electronics allowing for design flexibility. It also does not require recalibration if replaced in the field, is easily designed for double or triple redundancy and offers accuracy of 0.0001% of full scale.

In summary, the DIST sensor is a simple, economical and compact device that can make accurate and reliable linear measurements in almost any environment with only a single wire for power and signal. It is currently available in custom configurations for OEM users and is also available off-the-shelf in standard configurations.