Downhole sensors and equipment used for oil exploration and extraction must operate in pressure and temperature extremes while providing reliable feedback. Downhole, position sensors are used to monitor several important parameters. They measure line tension for wires and cables travelling through the borehole, cutter position to allow operators to accurately control drilling direction, and the bore casing radius to help find abnormalities requiring repair. Sensors must be robust, accurate, and reliable to accommodate drilling in sensitive areas and avoid costly down time or machine damage. Linear Variable Differential Transformers (LVDTs), often the position sensor of choice for downhole drilling applications, offer ruggedness in harsh environments, friction-free operation, excellent reliability, and infinite resolution for accurate and repeatable position feedback.
LVDTs have two components: a fixed housing and a separate movable core. When the housing is mounted to a fixed component, the core is mechanically linked to the measured object like a valve or extendable arm. As the measured object moves, the core travels through the fixed housing and changes the output of the LVDT proportional to position. Signal conditioning electronics convert the raw LVDT output to a DC or digital signal used by control systems.

LVDTs are available in a variety of configurations including rugged sealed packages for extreme temperature and pressure, or with subminiature designs featuring a ⅜ in. outer diameter and a low-mass core to fit in areas with limited space.

AC AND DC LVDTs

When using an AC-operated LVDT, the signal conditioning electronics are housed separately from the LVDT, allowing the sensor to enter extreme environments where circuitry could not survive. Electronics remain housed in a controlled environment while the AC LVDT is designed to enter smaller spaces and an expanded temperate range.

DC LVDTs contain a printed circuit board (PCB) with signal conditioning electronics that deliver DC voltage, current, or digital output directly from the sensor. While not typically used downhole because of the space and temperature restrictions, DC LVDTs can deliver measurements on surface equipment and transmit signals over long cable lengths (up to 1 mile) delivering position feedback in remote locations.

CONNECTORS OR LEAD WIRES

A connector or lead wire serves as the electrical connection between an LVDT and its signal conditioning electronics. The best method of connection depends on the specifics of the application and the environment where the LVDT operates.

Lead wires are typically the best choice in hydraulic applications with vented LVDTs operating at pressures and temperatures that can reach 30 000 psi and 400˚F. Vented LVDTs are designed so that hydraulic fluid completely penetrates the internal windings such that no pressure differential is created. Using a connector in hydraulics, where rapid pressure fluctuations are routine, might create a temporary sealing point or pressure pockets. When a pressure pocket is created, a very high amount of pressure can act on a component that is not designed to withstand it, causing damage or failure. In vented LVDTs, lead wires are configured to ensure fluid flows freely to accommodate sudden spikes and drops and all components are subjected to equalised pressure.

When the LVDT is exposed to downhole temperatures and fluids, either a glass-sealed hermetic connector or a fitting designed with threads and an accompanying O-ring are often required. A connector must be chosen to provide sealing for the internal LVDT components as well as the mating plug and electrical connections. Because drilling fluids and mud can be electrically conductive and corrosive, penetration of this fluid into the internal LVDT windings or external electrical connections can cause damage, a short circuit, or sensor failure. An alternative to a hermetic connector is to implement a fitting with threads and an O-ring groove. When the LVDT is threaded into the fixture, the O-ring engages and creates a seal so outside fluids do not penetrate. Maintaining a hermetic seal on all connections and internal components is critical to the continued operation of the LVDT.

HOW LVDTs ARE DESIGNED FOR COMMON DOWNHOLE REQUIREMENTS

As temperatures in downhole drilling can exceed 500˚F (260˚C), LVDT Linear Position Sensors are using new designs and materials to operate reliably. Today, LVDTs are constructed from a range of materials such as stainless steel, Inconel, or Monel to best fit the operating environment. In oil and gas applications where sensors are exposed to flammable or corrosive vapours and liquids, or operate in pressurised fluid, the sensor case and coil assembly can either be vented or hermetically sealed.

When used to control cutter directions, LVDTs are typically immersed in chemically and electrically inert hydraulic fluid and...
designed with a 400-series vented stainless steel housing. The vented housing equalises pressure inside and outside the LVDT so units can withstand a combination of high pressures, temperatures, shock and vibration and perform where space is limited. In addition to protecting the inner windings, the 400-series housing acts as a shield containing the magnetic field inside the LVDT for improved linearity and protection against outside electrical interference generated by adjacent equipment.

In some bore scope configurations, the LVDT is hermetically sealed as it is mounted externally and exposed to the corrosive and demanding downhole conditions. Exposed components can see a variety of fluids including sulfides, acids, drilling mud, and other corrosive chemicals all at pressures up to 20 000 psi and temperatures in excess of 400°F. To protect against the high pressure, LVDTs are constructed with special alloys, like Inconel 718, that offer exceptional yield and tensile strength to protect against corrosive drilling mud and pressures up to 20 000 psi (1380 bar). Since Inconel does not have magnetic shielding properties, ferromagnetic material like Mu-metal is placed internally surrounding the coils. LVDT cores can either be housed in an Inconel case or coated, making them impervious to many drilling fluids.

Whether vented or hermetically sealed, all LVDTs for downhole use share certain design features and methods. Internal coils are wound using high temperature magnet wire and tape, Teflon lead wires for chemical resistance and temperature ratings to 600°F (315°C), and special high melting point solder.

FUTURE DOWNHOLE REQUIREMENTS
To open previously inaccessible oil reserves and increase the output of existing reserves, future drilling equipment will operate at even higher temperatures. Recently discovered oil reserves, like Lula Oil Field (formerly Tupi Oil Field) off the coast of Brazil and 5000 m below the sea floor, are increasingly deep and more difficult to reach. When extracting oil from similar deep reserves, operating temperatures can approach 600°F (315°C).

LVDTs are well-positioned to meet these emerging requirements. New design techniques enable continuous operation up to 1000°F (538°C) while standing up to the harsh downhole environments. With the use of exotic electrical materials, ceramics, and special core materials for extreme temperature, LVDTs can continue to offer enhanced mechanical life with superior resolution and repeatability in the most demanding environments.