Oilfield Transducers

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With an increasing number of oilfields being computer automated, it is becoming important for field personnel to have an understanding of the associated automation equipment. An important part of this equipment, the end devices, are located in the field and perform electromechanical conversions of variables such as temperature, pressure, and flow. Measurement end devices, more properly termed transducers, fall into two categories—those which produce a continuous measurement of the variable in question and those which indicate a yes or no condition of a variable. The latter, often termed a go/no-go device, is essentially a switch which operates by sensing a value of the variable above or below a fixed, specified level. These switches are most often used as alarm indicators. For instance, one might indicate that the pressure in a pipeline is too high, or that the level of oil in a tank is too high. Sometimes, however, the switch may be used in a slow time constant loop as a controlling device. An example is the control of liquid level in a tank.

BASIC TYPES OF GO/NO-GO DEVICES

The oldest type of go/no-go device is the mechanically actuated switch. In this type of device the variable to be sensed is transformed into a position variable which in turn may move the contacts of a mechanical switch. In detecting liquid level, the position is obtained by using a float at the surface of the liquid, and the position of the float activates a switch contact. For pressure measurement, the pressure may be transformed into position by use of a flexible diaphragm, or by use of a Bourdon tube. Temperature measurement may be transformed into position by bimetallic strips, or by an intermediate transformation into pressure by using a compressible fluid inside a closed chamber.

Any variable which can be transformed into a position variable may be measured by a mechanically activated switch. The obvious disadvantage in this type device is the necessity for moving parts, often located in contact with crude oil or gas. Most oilfield people are well acquainted with this problem.

A second type of go/no-go device is the electrically activated switch. The switch in this instance is a relay, which switches when an electrical input increases above a fixed level. Hence, this type of device requires a transformation of the variable into an electrical signal. This transformation implies continuous measurement and will be discussed in detail later.

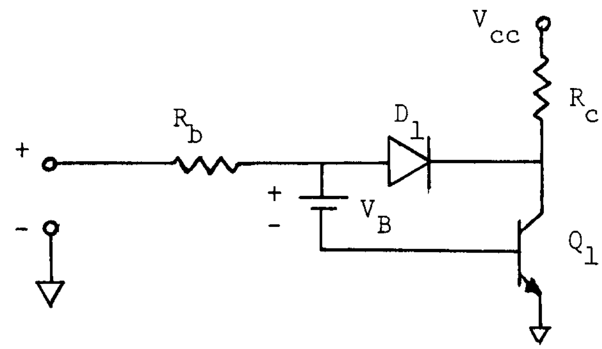

FIGURE 1

TRANSISTOR SWITCHING CIRCUIT

A third type of go/no-go, the electronic switch, is similar to the electrically activated switch in that it senses the level of an electrical signal. The electronic switch, however, is a high gain transistor, or tube amplifier, rather than a relay, and switch positions are indicated by voltage levels. A typical transistor switching circuit is shown in Fig. 1. Its chief characteristic is high voltage gain.

CONTINUOUS MEASUREMENT DEVICES

In an automation system employing a digital computer, continuous measurement of variables is not required. Each variable need be read only at intervals specified by the computer program. However, few transducers make sampling-type measurements of the variables found most often in oilfield projects. Instead, each transducer provides a continuous-type measurement whose output is eventually sampled by a multiplexer unit.

Both categories of transducers may be further classified as those with an analog output and those with a digital output.

ANALOG OUTPUT TRANSDUCERS

This category of transducers converts the mechanical variable in question into a continuous electrical signal. The signal may be either a voltage level, current level, or frequency depending upon the particular installation. If the output is ready nearby (physical distance is short), voltage outputs are satisfactory and usually cheaper than current outputs. However, voltage drops along cables and noise pickup can cause unwanted error, especially if the signal lines become long. In this case, the current-output device is used; current-output devices are more expensive because they contain a voltage-controlled current source which converts the voltage output of a standard transducer into a fixed current. It is easily seen that unless voltage drops along the wires are excessive, no error results in the long distance transmission of a current signal. The frequency output is used most often when a counting or accumulation output is desired, or for analog transmission over radio/microwave channels.

Some devices provide a direct change of the mechanical variable into an electrical signal. These devices are made of a material whose electrical properties change with respect to the mechanical variable. These properties include resistance, capacitance, inductance, and voltage.

Analog Transducer Devices

Thermocouples are probably the most widely used transducers for temperature measurements. When two dissimilar metals are joined together, a potential difference is generated across the junction. This is known as the Seebeck Effect. The potential difference is a function of the temperature of the junction. When a loop is formed of two dissimilar wires, the net potential difference generated in the loop is a measure of the temperature difference between the two junctions. If one of the junctions is kept at a known reference temperature, the EMF generated in the circuit is a measure of the absolute temperature of the second junction.

Thermocouples may be used for an extremely broad temperature range (up to about 4000°F) and are excellent for point sensing. Unfortunately, their accuracy is limited by low-level outputs (millivolts), the need for a supporting temperature measurement (reference junction), and susceptibility to environmental effects such as corrosion and vibration.

Thermistors are small bits of semiconductor material, such as silicon carbide, that exhibit a negative temperature coefficient. The rate of change of resistance with temperature is very large and nonlinear—about ten times that of metals. Most available devices cover the range from -100° to +600°F, but recent work may lead to thermistors that function as low as -445°F and as high as 2700°F. In use, the thermistor has two problems—it has a relatively long response time and is quite fragile. Also, any given type is usually suited only to a relatively restricted temperature range.

Piezoelectric Crystals—In crystals, a piezoelectric effect is produced when solid crystalline dielectrics (such as barium titanate,

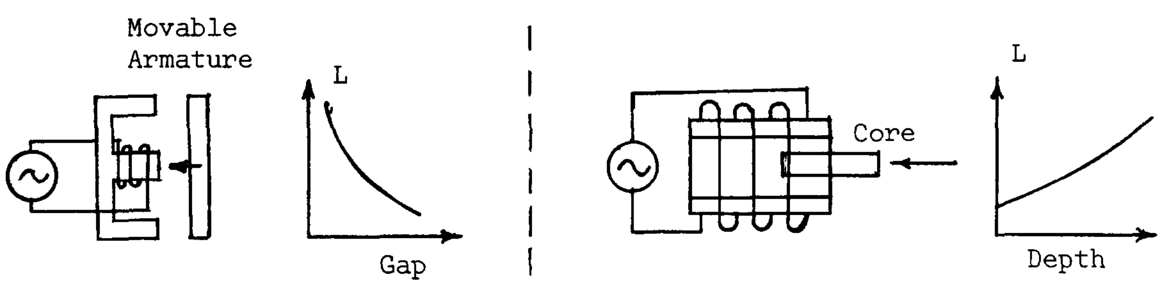

FIGURE 2
VARIABLE INDUCTORS

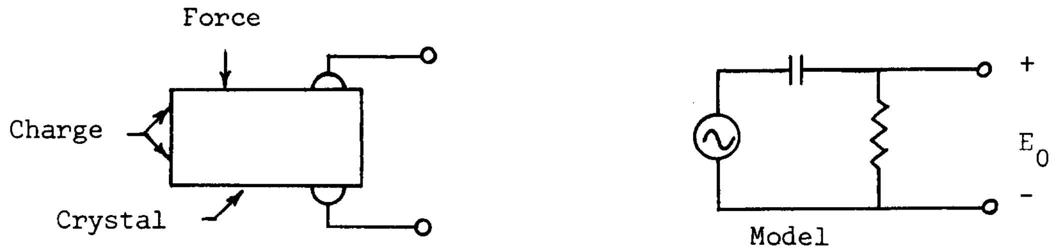

FIGURE 3

PIEZOELECTRIC CRYSTAL

Rochelle salt or quartz) are deformed. The deformation of the crystal lattice causes a relative displacement of the positive and negative charges within the lattice. This internal charge displacement produces an external charge, which can be measured by applying electrodes to opposite surfaces of the crystal and measuring the potential difference between them. (See Fig. 3)

Piezoelectric transducers are small, have high output and good high frequency response. But they lack a DC response, are very sensitive to temperature and humidity, and require a very high impedance monitor system.

Strain Gauges, (Fig. 4), are the most common transducer elements; their greatest advantage is their small size. The guages operate on the principle of mechanical distortion producing a changing resistance. Many gauges used today are constructed of thin-film or semiconductor materials. Distortion is typically along their length and/or their cross-sectional area, and results in a resistance change. Strain gauges may be excited by AC or DC sources, and may be used for both static or dynamic measurements. They are commonly used in a four-leg bridge, and are relatively insensitive to temperature, shock, and vibration effects.

In an unbonded strain gauge one end is fixed while the other is attached to a movable mass. Primary usage is for measuring displacement. Typically, accuracy is about one per cent.

The figure merit of a strain gauge is the gauge factor, and is defined as the relative change in resistance ($\Delta R/R$) divided by the relative change in length of the resistive element ($\Delta L/L$). With a gauge factor of 3 or 4, unbonded strain gauges offer high sensitivity. Accuracy, however, tends to deteriorate with aging, because of creep, hysteresis and strain relief.

A bonded strain gauge transducer is also comprised of resistive elements in a bridge configuration—but the whole bridge is firmly attached to the structure under investigation. Wire gauges are usually first attached to a paper which, in turn, is attached with an adhesive to the member under study. As the member distorts and deflects, resistance variations are produced in the gauge.

Bonded gauges are more stable than unbonded gauges, but are less sensitive. Gauge factors are typically 2, and accuracy is about one per cent.

With the ever-present penchant for size reduction, thin-film resistor gauges are coming into their own. The thin-film device performs much like a bonded wire gauge, except that external temperature compensation is not required because their fabrication optimizes the quired because their fabrication optimizes thermal paths and reduces temperature gradients.

Semiconductor strain gauges similar to the thin-film types are also commercially available; they provide high outputs (measured in volts) and high gauge factors (200 and higher). Thermal and stability characteristics of units vary from fair to very good, depending on the type in question.

Not all transducers make direct conversions of mechanical variables into electrical variables. Many use a mechanical transformation into a position, similar to the go/no-go scheme discussed earlier. In this case, however, the mechanical position is measured continuously by one of several schemes.

Linear Voltage Differential Transformer (LVDT)—With a differential transformer transducer, (Fig. 5), the force, pressure, acceleration, or other parameter being measured displaces a magnetic core inside the transformer. As the core is displaced in either one direction or the other, the amount of coupling with the output coils changes to cause an imbalance in induced EMF. The result is a linear output.

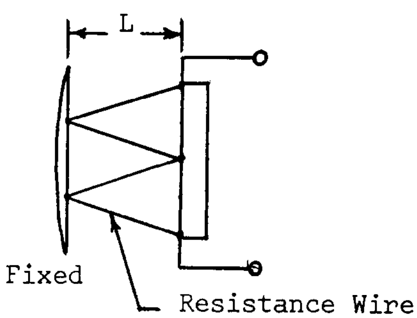

FIGURE 4

UNBONDED STRAIN GAUGE

The output is high-level (in volts), but AC excitation and large displacements are needed.

Potentiometric Transducers, (Fig. 6), consist of a continuous resistive element with a sliding contact pick-off. Displacement of the "wiper" on the resistive element—which might be a wire-bound, carbon, or deposited thin-film type—is through a mechanical linkage from the measurand (pressure, acceleration, and so forth). The output of a potentiometer may be linear, trigonometric, logarithmic, or otherwise nonlinear, depending on the construction of the resistive element.

Pot transducers are simple, versatile, and are suitable for AC and DC applications. They are inexpensive and can be biased to eliminate the need for amplifiers. They are, however, large, noisy, short-lived, and have low frequency responses and a high sensitivity to vibration.

Force Balance Principle

Any time a position measurement is made with an analog device, the implication is present that some force caused the original displacement. For instance, when using a diaphragm to measure pressure, the force of the pressure acting on the diaphragm causes it to displace. In fact, if one holds the diaphragm in a fixed position, then the force required to do so is proportional to the measured variable, pressure. One may use this principle to eliminate the disadvantage of moving parts in position measurements as described below.

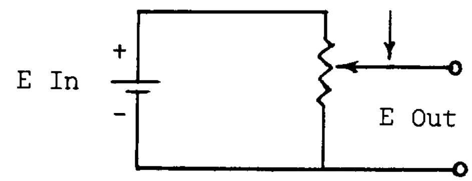

FIGURE 6

POTENTIOMETRIC TRANSDUCER

On the force-balance or restoring force transducer, the output of an LVDT or pot is amplified and integrated as shown in Fig. 7. The output of the integrator is used to drive a solenoid, motor, or other force-producing element in such a manner as to oppose the measured force. The total displacement is then zero, and the output of the integrator is an accurate measurement of the input force. Force balance transducers are very accurate and reliable, but are more expensive than other transducers.

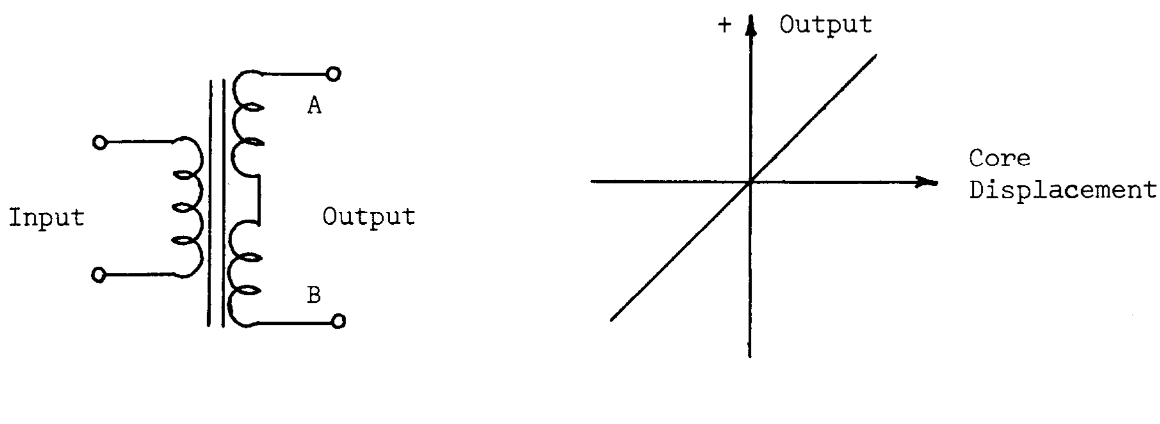

FIGURE 5

DIFFERENTIAL TRANSFORMER

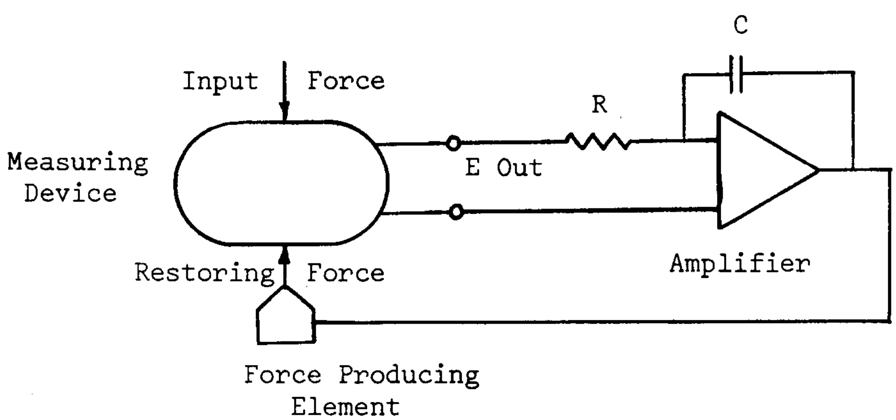

FIGURE 7

FORCE BALANCE TRANSDUCER

DIGITAL OUTPUT TRANSDUCERS

When measured variables are transmitted over long distance communication channels, the need for accuracy usually dictates that digital (numeric) signals be transmitted. The electrical output of analog transducers is converted to digital signals in a box known as an analog-to-digital converter (A/D). In some products, the A/D converter may be a physical part of the transducer itself. This setup is sometimes considered to be a digital output transducer. It is possible, however, to make certain transducers whose only internal electrical signal is a digital signal. Such a device is called a "true digital" transducer.

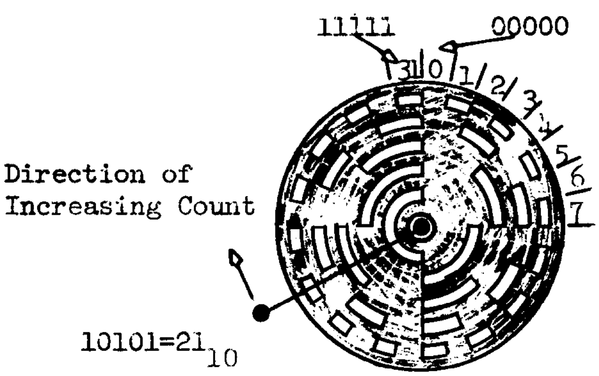

FIGURE 8

BINARY CODED STRAIGHT DISC

Despite the growth of digital electronics, there is virtually only one truly digital transducer—the shaft angle encoder. Other so called "digital transducers" simply operate on an input from another source (such as a pulse train), or contain digitizing electronics that convert the analog signal.

By proper coupling of the encoder's input shaft, its output can be made to represent angular or linear position, velocity, or acceleration.

Whether mechanical, magnetic, capacitive, or optical techniques are used to detect the input information, operation of all encoders is quite similar. A coded disc is rigidly attached to an input shaft. Then the code is read by suitable electronic detectors as the shaft is rotated.

For example, referring to Fig. 8, the disc is coded in a straight binary notation, and has a resolution of 5 binary bits (the circle is divided into 32 increments). The code pattern consists of 5 tracks of alternately clear and opaque segments. One detector is used for each track, with outputs determined by the pattern on the disc.

As an example, consider the case when the

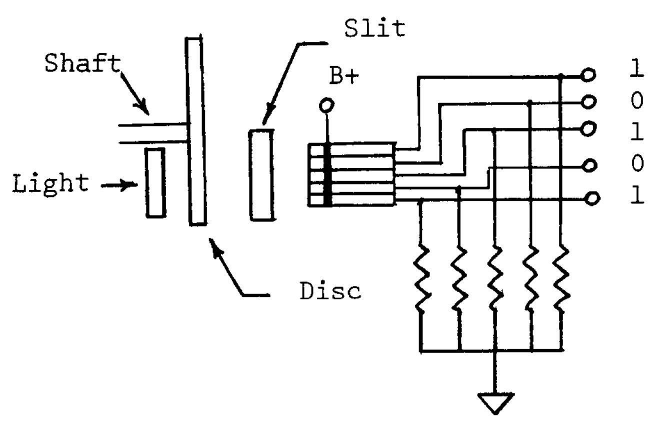

FIGURE 9

PHOTOELECTRIC SHAFT POSITION ENCODER

read-out slit is in the position indicated by the line on the coded disc. The inside track represents the most significant bit and the read-out would be 10101, or a decimal, 21. Optical encoders are commercially available with up to 20 tracks, dividing a circle into more than a million segments.

Another technique is an extension of the force balance principle. In this case, the integrator is replaced by an electrical counter so that inputs from the transducer above a certain threshold cause the counter to increment. A digital to analog converter is then employed to convert the counter's digital output into a continuous restoring force.