MAGNETOSTRICTION AND ITS APPLICATION TO LIQUID LEVEL MEASUREMENT

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In ancient times men knew that a special kind of rock could pull other rocks of the same kind and other rocks (such as iron) towards itself. In modern times man uses the same force exerted by these ancient 'lodestones' to generate electricity, store information in computers, to see inside a living person's body without surgery, and to see inside a closed vessel to find the liquid level. Magnetism is a fundamental force closely related to electricity. They are basically a single force, expressed in two different ways. The force is called electromagnetic force. A magnet can attract or repel another magnet without touching it. In fact, magnetic force is exerted even when empty space, air, or any non-magnetic material such as stainless steel, separates the two from each other.

Background

In 1820, a Danish physicist, Hans Oersted, established that electric current flowing through a wire makes up a magnetic field that curves around the wire. The direction of the magnetic field follows the right hand rule. This rule states that if the thumb of the right hand is pointed in the direction of the current flow, from positive pole to negative, then the fingers curl in the direction of the magnetic field.

Oersted's discovery led to speculation that if an outside magnetic field were applied the to the magnetic field created by a conducting wire, the interaction of the magnetic field could cause the wire to rotate, or that if the wire were held in place, that the external magnet would rotate. Michael Faraday was able to prove this theory true with his experiments in the mid 1820s. -This is magnetostriction.

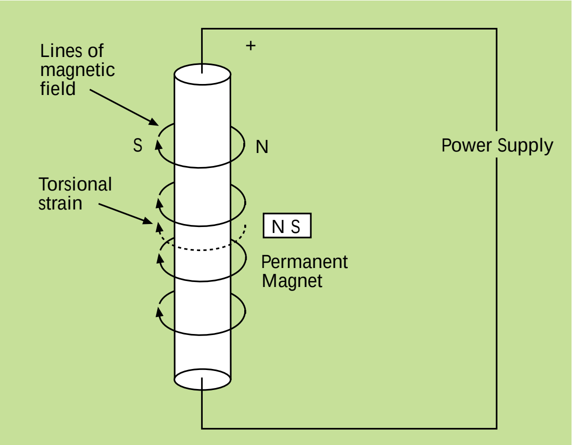

Figure 1
Torsional strain is produced by placing a permanent magnet close to a current carrying conductor

James Maxwell published a paper in1864 describing his theory of how a magnetic disturbance caused by a moving electrical charge, would travel. He said that this disturbance could be treated as a wave and it would travel at the speed of light. Maxwell concluded that light was an electromagnetic wave. Electromagnetic wave theory states that such waves consist of the growth and collapse of electric and magnetic fields, which exist at right angles to each other.

Therefore, if the electric signal is a short duration pulse travelling down the wire, the electrically induced magnetic field will also be travelling down the outside of the wire at 90° to the line of travel of the electric pulse, at the same time and speed as the electrical pulse. When the permanent magnet is placed close to the conducting wire, as shown in *Figure 1*, it induces a torsion strain in the wire at the instant that the magnetic field passes the permanent magnet's field. This torsion pulse travels in both directions along the wire at a constant speed.

Electrical pulses travel through wires at the speed of light. Torsion pulses travel along a wire at the speed of sound. Therefore, to apply this technology to everyday use required an advance in the ability to measure very high-speed signals and time their travel through a conducting media as well as advances the production of special conducting media. We also need a way to measure the extremely small torsion produced in the wire.

We know the length of wire, the start time, the speed of the electrical signal the speed of the torsion signal and we measure the time between the start pulse leaving and the torsion pulse returning. This leaves only one variable, the distance traveled by the torsion pulse - or, more properly stated - the position of the permanent magnet along the wire.

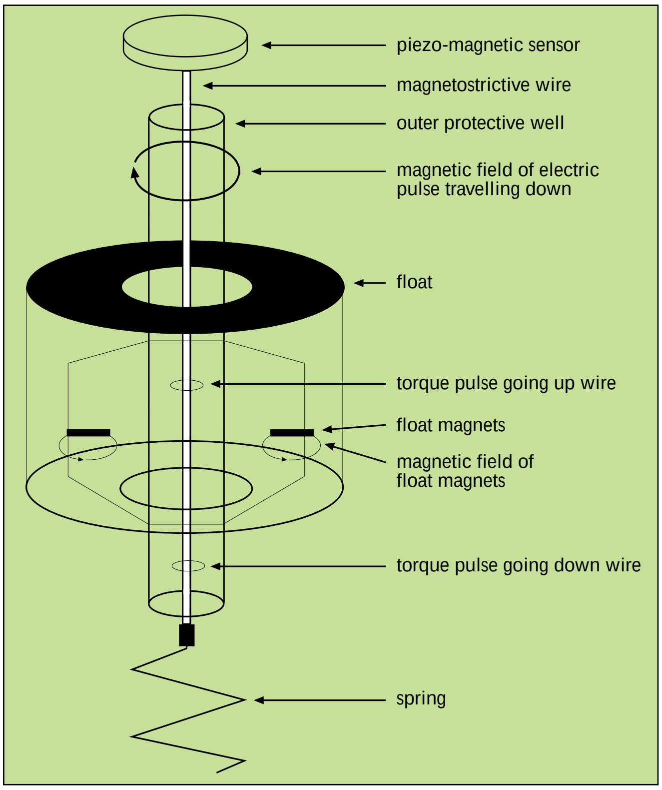

Figure 2
The application of magnetostrictive technology to liquid level measurement

Application

Magnetostrictive technology has been around and in use in industry for some time. The outstanding repeatability of the technology lent itself to the control of machines, especially robots. This is an application where precise movement and fast, extremely accurate feedback of actual position are critical to the operation of the machines. Recently it has also been applied to the measurement of liquid level.

As shown in *Figure 2*, the magnetostrictive wire is pulsed with a low voltage pulse several times per second. This electric pulse carries with it a magnetic field following the right hand rule, down the outside of the wire. The wire is suspended between the piezo-magnetic crystal sensor at the top and the tension spring attached to the bottom of the protective non-magnetic well. Outside the well, in the liquid to be measured, is a non-magnetic (usually 316 stainless steel), hermetically sealed float with permanent magnets inside it, pointed towards the magnetostrictive wire. This float is designed to float partially submerged (typically 75%) in a liquid at a particular specific gravity. This ensures the highest accuracy of measurement of the actual liquid level without any 'offset' due to floats made for a range of specific gravities. When the magnetic pulse reaches the magnetic field of the permanent magnets in the float, which is floating on the liquid, the magnetic fields react. This reaction causes a torque in the wire which propagates as a torsion wave both up and down the wire. The down- ward pulse is absorbed by the spring. The upward travelling pulse is felt by the piezo-magnetic crystal sensor at the head of the unit. The microprocessor electronic circuit made note of the time of the electric pulse starting down the wire and it measures the time taken for the torque pulse to reach the piezo-magnetic crystal. The circuit then does a differential time versus speed calculation to determine the distance from the head to the float.

Aspects of construction

One critical factor in the design of the magnetostrictive level devices is the make-up of the wire. Most metals and alloys have a negative temperature coefficient modulus of elasticity; that is to say, they lose stiffness when heated. They also have a positive coefficient of thermal expansion, increasing length when heated. These two effects are due to an increase in the energy of the atoms with the increase in temperature. Some ferromagnetic materials, however, exhibit very different behaviour, which can be used to design constant modulus alloys.

Another one of the critical portions of the basic design of magnetostrictive level devices is the means of sensing the torsion return pulse. Several manufacturers use strain gauges to sense the torsion pulse on the wire. Strain gauges are notoriously temperature and vibration sensitive. These tendencies cause the level instrument to suffer the same inaccuracies as differential pressure transmitters do because of the effects of temperature and pressure changes in the process.

The modulus of elasticity (E) of ferromagnetic materials is a complex function of a number of physical properties, related by the following equation:

$$E = (4\pi\,(\lambda^2\,\mu)/k^2$$

where:

λ = magnetostrictive constant

μ = reversible permeability

k = electromechanical coupling coefficient

Each of the factors λ, μ, and k is affected by composition, strain and temperature. To ensure that the modulus of elasticity remains constant with variations in temperature, it is necessary to select a composition for which $\lambda^2\mu$ changes at the same rate and in the same direction as k^2, therefore canceling each other out. Because of the properties of the special magnetostrictive wire and the characteristics of the piezo-magnetic-crystal sensor, there is no effect on the measurement accuracy because of changes in process temperature. Since the measurement system does not depend on pressure changes in the process and, in fact, is isolated from them by the protective well, there is no effect on this system because of changes in process pressure. Unlike differential pressure transmitters which depend on the weight of the liquid rising or falling to infer the level, this measurement system is simply seeking the presence of a magnet along the length of the measuring wire; there is no effect on the measurement due to hysteresis, it does not care whether the level is rising or falling.

All of these factors negatively influence the measurement accuracy of the level if differential pressure transmitters are the means of measurement. Changes in specific gravity of the process liquid have 1/100th of the effect on the measurement using magnetostrictive transmitters as when using a differential pressure transmitter.

Dielectric constant changes in the process liquid have no effect on magnetostrictive transmitters. They have a very negative effect on the accuracy of a conductivity level measurement.

A proven technology

Measuring liquid levels in many process vessels requires an accurate, reliable and repeatable measurement. This should come in an easy to install and maintain, rugged package. Magnetostriction is a proven technology that has been used in a variety of applications over the years. Thomas Edison used this principle in his first Frequency Modulated radio power tubes, and it was used for core memory in early mainframe acceptance computers. It gained wide acceptance because it is a true linear measurement of linear variables. It is now the primary technology throughout the world for machine control positioning and robotics as a linear displacement transducer (LDT). From this outstanding success it was only a small step to the measurement of liquid levels. This technology provides the most outstanding accuracy and, more importantly repeatability of any current measurement system. The typical accuracy of a differential pressure (DP) transmitter is 0,25% of full scale measurement or sometimes of transmitter total range. A modern smart transmitter might be as accurate as 0,1 % of full scale measurement. DP transmitters perform so poorly in the repeatability category that their specification sheets rarely even state the repeatability.

Magnetostrictive transmitters are typically accurate to 0,01% of full scale measurement. The repeatability is typically 0,005% of full scale measurement, which translates into a repeatability of 0,038 cm in a 750 cm tank!

Conclusion

Magnetostrictive transmitters are available as explosion proof and/or intrinsically safe, with digital communications and two wire 24 V, 4-20 mA current loop. Units come in probe lengths from 30 cm to 22,5 m, and in a variety of process wetted materials. They are good for process pressures up to 3 000 psi and can withstand process temperatures of up to 4500C..

This is a well-proven technology which can now be applied to any level measurement where float operated devices will work. provides out-standing accuracy repeatability, ease of calibration and installation and has only one moving part - the float. It is a long-lasting, simple, direct linear measurement device.